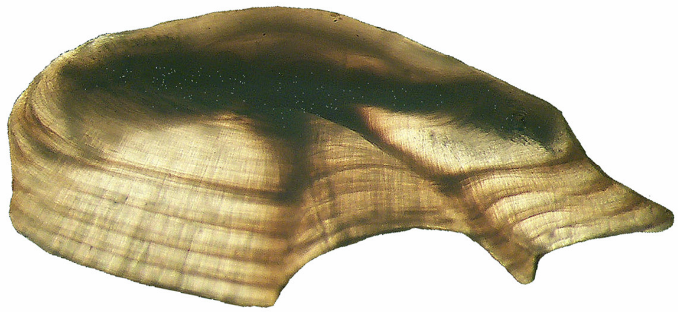
Final Report for 2007 Virginia - Chesapeake Bay Finfish Ageing



by

Hongsheng Liao, Cynthia M. Jones,
Christina D. Morgan, and Joseph C. Ballenger

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October 31, 2008

Final Report

Finfish Ageing for Virginia Catches and
Application of Virtual Population Analysis to
Provide Management Advice

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Table of Contents

Page

Table of Contents (continued)

Chapter 14 Sheepshead

Executive Summary

In this report we present the ageing results of 14 finfish species collected from commercial and recreational catches made in the Chesapeake Bay and Atlantic waters of Virginia, U.S.A. in 2007. All fish were collected in 2007 by the Virginia Marine Resources Commission's (VMRC) Stock Assessment Program and aged in 2008 at the Center for Quantitative Fisheries Ecology's (CQFE) Ageing Laboratory at Old Dominion University. This report is broken down into chapters, one for each of the 14 species we aged. For each species, we present measures of ageing precision, graphs of year-class distributions, and age-length keys. In addition, in Chapter 14 we summarize the results of our research on sheepshead (*Archosargus probatocephalus*) population dynamics in the Chesapeake Bay of Virginia between 2006 and 2008, including sheepshead data collection, growth, and reproductive status.

We used three calcified structures (hard-parts) to age our species. Specifically, two calcified structures were used for determining fish ages of the following three species: striped bass, *Morone saxatilis*, (n = 800); summer flounder, *Paralichthys dentatus*, (n = 540); and tautog, *Tautoga onitis*, (n = 237). Scales and otoliths were used to age summer flounder and striped bass, and opercula and otoliths were used to age tautog. Comparing alternative hard-parts allowed us to assess their usefulness in determining fish age as well as the relative precision of each structure. Ages were determined from otoliths for the following species collected in Virginia waters during 2007: Atlantic croaker, *Micropogonias undulatus*, (n = 344); black drum, *Pogonias cromis*, (n = 48); bluefish, *Pomatomus saltatrix*, (n = 374); cobia, *Rachycentron canadum*, (n = 62); red drum, *Sciaenops ocellatus*, (n = 101); spadefish, *Chaetodipterus faber*, (n = 292); Spanish mackerel, *Scomberomorous maculates*, (n = 250); Sheepshead (n = 82); spot, *Leiostomus xanthurus*, (n = 246); spotted seatrout, *Cynoscion nebulosus*, (n = 186); and weakfish, *Cynoscion regalis*, (n = 422). In total, we made 10,330 age readings from 6,593 scales, otoliths and opercula collected during 2007. A summary of the age ranges for all species aged is presented in Table I.

Starting this year, we will estimate and report sample sizes and coefficient of variation (CV) for estimates of age composition for the following species: Atlantic croaker, bluefish, spadefish, Spanish mackerel, spot, spotted seatrout, striped bass, summer flounder, tautog, and weakfish. The sample sizes and the CVs enabled us to know how many fish we need to age in each length interval and to measure the precision for estimates of major age classes in each species, respectively, enhancing our efficiency and effectiveness on ageing those species.

As part of our continued public outreach focused in marine fisheries biology and management, we participated in the Sea Camp organized by the Department of Ocean, Earth, and Atmospheric Sciences at Old Dominion University during the summer of 2007. The Sea Camp is designed to educate middle and high school students about marine resources management and environmental protection. To support other environmental and wildlife agencies, and charities, we donated more than 5,700 pounds of dissected fish to Wildlife

Response, Inc.- a local wildlife rescue agency which is responsible for saving injured animals found by the public- and the Salvation Army.

In 2007, we continued to upgrade our Age & Growth Laboratory website, which can be accessed at http://www.odu.edu/fish.The website includes an electronic version of this document and our previous VMRC final reports- from 1999 to 2006. The site also provides more detailed explanations of the methods and structures we use in age determination.

Table I. The minimum and maximum ages, number of fish, hard-parts, and age readings for the14 finfish species collected and aged in 2007.

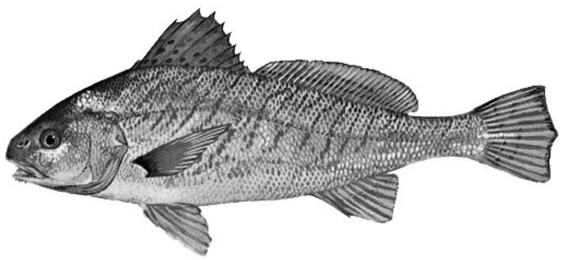
Species	Number of Fish	Number of Hard-Parts	Number of Age Readings	Minimum Age	Maximum Age
Atlantic croaker	558	558	688	1	14
Black drum	48	48	96	0	64
Bluefish	443	443	748	0	11
Cobia	65	62	124	1	14
Red drum	102	101	202	1	3
Spadefish	368	368	584	0	17
Spanish mackerel	270	250	500	0	8
Sheepshead	82	82	164	1	35
Spot	343	343	492	0	5
Spotted seatrout	293	293	372	0	9
Striped bass	908	1440	2664	3	24
Summer flounder	1292	1715	1926	1	13
Tautog	242	468	926	2	23
Weakfish	848	422	844	1	6
Totals	5862	6593	10330		

Acknowledgements

We thank Lakshmi Chaitanya, Billy Culver, and James Davies for their technical expertise in preparing otoliths, scales, and opercula for age determination. They all put in long hours processing “tons” of fish in our lab. We are also thankful for Dr. William Persons’ III hard work on our *Species Updates* and web page. A special note of appreciation to Ron Owens, Troy Thompson, Joanie Beatley, Richard Hancock, and Myra Thompson for their many efforts in this cooperative project. We would like also to thank our Ph. D. students Joey Ballenger, Stacy Beharry, and Nuno Prista, masters student Renee Reilly and Postdoc Jason Schaffler for their help in processing fish whenever we were short of hands. Finally, we would like to thank the Virginia Coastal Conservation Association (VA CCA), local recreational anglers, angler clubs, and marinas for their efforts to make sheepshead collection possible.

The image on the front cover is an otolith thin-section from a 315 mm (12.4 inch) total length, 5 year-old male spot. The fifth annulus is forming at the edge of the otolith.

Chapter 1
Atlantic Croaker



Micropogonias undulatus

INTRODUCTION

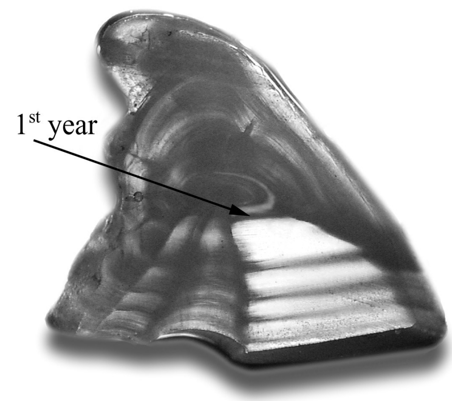
We aged a total of 344 Atlantic croaker, *Micropogonias undulatus*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The croaker ages ranged from 1 to 14 years oldwith an average age of 6.5, and hada standard deviation of 2.43, and a standard error of 0.10. Fourteen age classes (1 to 14) were represented, comprising fish from the 1993 through 2006 year-classes. Fish from the 2001 year-class dominated the sample.

METHODS

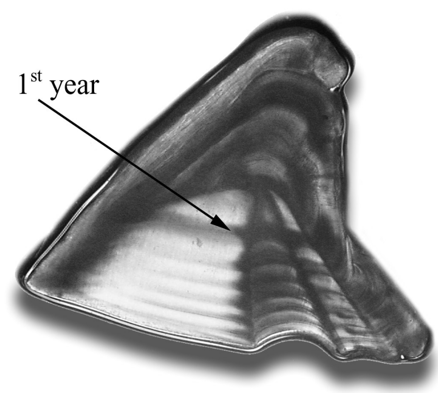
Sample size for ageing — We estimated sample size for ageing croaker in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively.The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing croaker in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of croaker collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of croaker used by VMRC to estimate length



(a)



(b)

Figure 1. Otolith cross-sections of a) a 5 year old croaker with a small 1st annulus, and b) a 6 year old croaker with a large 1st annulus.

distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) will be obtained. Therefore, the criterion to decide *A* is that *A* should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory identification number. All otoliths were stored dry in their original VMRC coin envelopes.

Preparation — Otoliths were processed following the methods described in Barbieri et al. (1994) with a few modifications. Briefly, the left or right sagittal otolith was randomly selected and attached to a glass slide with Electron Microscopy Sciences' clear Crystalbond™ 509 adhesive. At least one transverse cross-section was cut through the core of each otolith using a Buehler Isomet low-speed saw equipped with two, three inch, fine- grit Norton diamond-wheel wafering blades, separated by a spacer of 0.3mm. Otolith sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but, more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Sectioned otoliths were aged by two readers using a Leica MZ-12 stereomicroscope under transmitted light and dark-field polarization at between 8 and 20 times magnification. Each reader aged all of the otolith samples. The ageing criteria reported in Barbieri et al. (1994) were used in age determination, particularly regarding the location of the first annulus (Figure 1).

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 374 for ageing croaker in 2007, ranging in length interval from 6 to 25 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 12% for age 5 and the largest CV of 24% for age 10 fish. In 2007, we randomly selected and aged 344 fish from 558 croaker collected by VMRC. We fell short in our over-all collections for this optimal length-class sampling estimate by 34 fish, however these were primarily from the very large and small length intervals (Table 1), therefore, the precision for the estimates of major age groups (such as age 2 and 3) would not be influenced significantly.

The measurement of reader self-precision was very high for both readers (Reader 1's CV = 0.7% and Reader 2's CV = 0). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 6$, df = 5, $P = 0.3062$). Figure 2 illustrates that the between-readers' precision of age estimates with an average CV of 0.2% was not significant with an agreement of 98% between two readers.

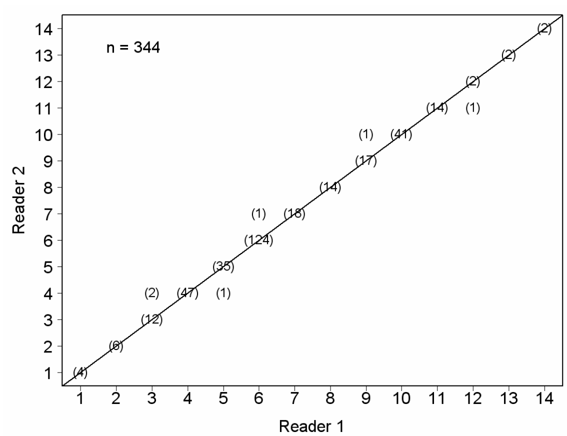


Figure 2. Between-reader comparison of otolith age estimates for Atlantic croaker in 2007.

Of the 344 fish aged with otoliths, 14 age classes (1 to 14) were represented (Table 2). The average age was 6.5 years, and the standard deviation and standard error were 2.43 and 0.10, respectively.

Year-class data (Figure 3) show that the fishery was comprised of 14 year-classes, comprising fish from the 1993-2006 year-classes, with fish primarily from the 2001 year-class. The ratio of males to females was a little les than 1:2 in the sample collected in. "Unknown" sex fish in the graph were either juveniles or had damaged gonads.

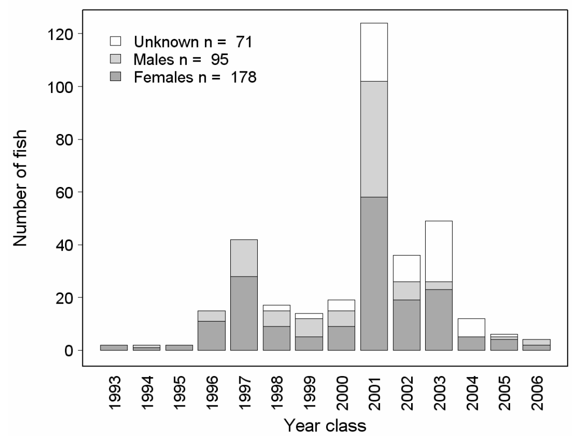


Figure 3. Year-class frequency distribution for Atlantic croaker collected for ageing in 2007. Distribution is broken down by sex.

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

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List of Tables

Table 1. Number of Atlantic croaker collected, and aged in each 1-inch length interval in 2007. Values in the column Target represent the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
6	5	4	4	1
7	5	2	2	3
8	5	4	4	1
9	15	57	15	0
10	23	85	25	0
11	38	59	38	0
12	71	92	71	0
13	52	69	52	0
14	40	48	41	0
15	34	55	34	0
16	27	44	27	0
17	16	20	16	0
18	8	13	9	0
19	5	5	5	0
20	5	0	0	5
21	5	0	0	5
22	5	0	0	5
23	5	0	0	5
24	5	0	0	5
25	5	1	1	4
Totals	374	558	344	34

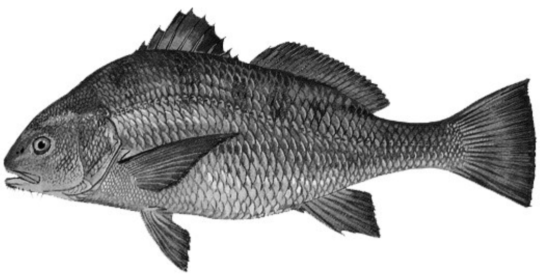
Table 2. The number of Atlantic croaker assigned to each total length-at-age category for 344 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Totals
6	3	1	0	0	0	0	0	0	0	0	0	0	0	0	4
7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	2
8	0	3	0	1	0	0	0	0	0	0	0	0	0	0	4
9	0	1	3	10	1	0	0	0	0	0	0	0	0	0	15
10	0	0	5	13	5	2	0	0	0	0	0	0	0	0	25
11	0	0	2	15	8	8	2	2	1	0	0	0	0	0	38
12	0	0	2	6	11	38	7	4	2	1	0	0	0	0	71
13	0	0	0	2	8	32	4	2	1	2	1	0	0	0	52
14	0	0	0	2	2	18	4	1	4	6	2	0	1	1	41
15	0	0	0	0	1	15	1	2	2	11	2	0	0	0	34
16	0	0	0	0	0	9	1	1	3	9	3	0	1	0	27
17	0	0	0	0	0	2	0	1	1	5	4	2	0	1	16
18	0	0	0	0	0	0	0	0	3	3	3	0	0	0	9
19	0	0	0	0	0	0	0	0	0	5	0	0	0	0	5
25	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
Totals	4	6	12	49	36	124	19	14	17	42	15	2	2	2	344

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Atlantic croaker sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	13	14
6	0.750	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.750	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.067	0.200	0.667	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.200	0.520	0.200	0.080	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.053	0.395	0.211	0.211	0.053	0.053	0.026	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.028	0.085	0.155	0.535	0.099	0.056	0.028	0.014	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.038	0.154	0.615	0.077	0.038	0.019	0.038	0.019	0.000	0.000	0.000
14	0.000	0.000	0.000	0.049	0.049	0.439	0.098	0.024	0.098	0.146	0.049	0.000	0.024	0.024
15	0.000	0.000	0.000	0.000	0.029	0.441	0.029	0.059	0.059	0.324	0.059	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.333	0.037	0.037	0.111	0.333	0.111	0.000	0.037	0.000
17	0.000	0.000	0.000	0.000	0.000	0.125	0.000	0.062	0.062	0.312	0.250	0.125	0.000	0.062
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000

Chapter 2
Black Drum



Pogonias cromis

INTRODUCTION

A total of 48 black drum, *Pogonias cromis*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The average age of the sample was 33.8 years, with a standard deviation of 18.03 and a standard error of 2.6. Twenty-six age classes were represented with the youngest age of 0 and the oldest age of 64 years, comprising fish from the earliest year-class of 1943 to the most recent year-class of 2007.

METHODS

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. In the lab they were sorted by date of capture, their envelope labels were verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory sample number. All otoliths were stored dry in their original VMRC coin envelopes.

Preparation — Otoliths were processed for ageing following the methods described in Bobko (1991) and Jones and Wells (1998). Briefly, at least one transverse cross-section was cut through the nucleus of each otolith with a Buehler Isomet low-speed saw equipped with two three-inch, fine grit Norton diamond-wafering blades, separated by a 0.3mm steel spacer. Otolith sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Sectioned otoliths were aged by two different readers using a Leica MZ-12 dissecting microscope with transmitted light at between 8 and 20 times magnification (Figure 1). Each reader aged all of the otolith samples.

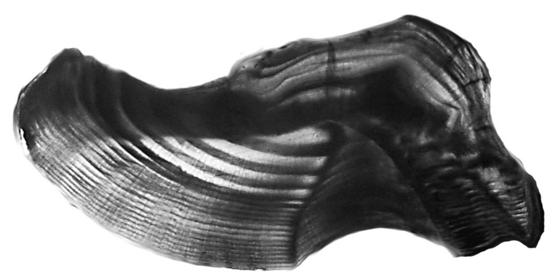


Figure 1. Otolith thin-section from a 20 year-old black drum.

All samples were aged in chronological order, based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — Reader 1 and 2 aged all fish for a second time to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

Measurements of reader self-precision were high for both readers (Reader 1's CV = 1.2 and Reader 2's CV = 0.8). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: χ^2 = 15.33, df = 13, P = 0.2870). Figure 2 illustrates the between readers' precision of age estimates. The average coefficient of variation (CV) of 1% was not significant. The between-reader agreement for otoliths for one year or less was 83% of all aged fish.

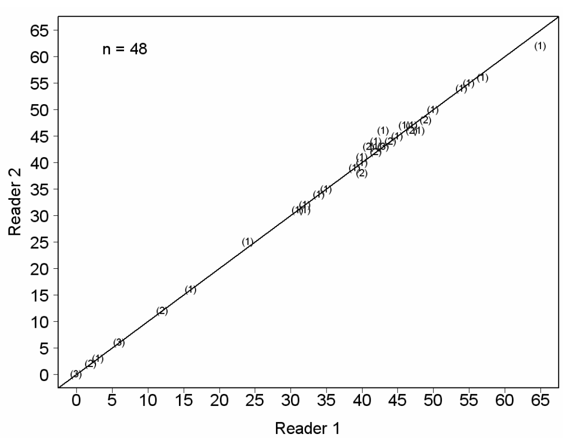


Figure 2. Between-reader comparison of otolith age estimates for black drum in 2007.

Of the 48 fish aged with otoliths, 26 age classes were represented (Table 1). The average age of the sample was 33.8 years, with a standard deviation of 18.03 and a standard error of 2.6. The youngest fish was a 0 year old and the oldest fish was 64 years old, representing the year-classes as early as 1943 and as late as 2007 (Figure 3).

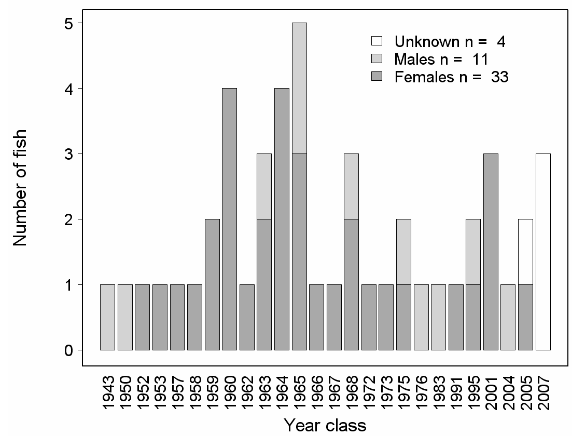


Figure 3. Year-class frequency distribution for black drum collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex fish were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 2 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

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Table 1. The number of black drum assigned to each total length-at-age category for 48 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years)								
	0	2	3	6	12	16	24	31	32
8	0	0	1	0	0	0	0	0	0
9	3	0	0	0	0	0	0	0	0
20	0	1	0	0	0	0	0	0	0
22	0	1	0	0	0	0	0	0	0
30	0	0	0	1	0	0	0	0	0
31	0	0	0	1	0	0	0	0	0
32	0	0	0	1	0	0	0	0	0
36	0	0	0	0	1	0	0	0	0
39	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	1	0	0
45	0	0	0	0	0	1	0	0	0
46	0	0	0	0	1	0	0	1	0
47	0	0	0	0	0	0	0	0	1
48	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0
Totals	3	2	1	3	2	1	1	1	2

Table 1. Continued

Length 1-inch interval	Age (years) 34	35	39	40	41	42	43	44	45
8	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0
42	0	0	1	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0
45	1	0	0	0	0	0	1	1	0
46	0	0	0	0	0	1	0	1	0
47	0	0	2	0	0	0	0	0	0
48	0	0	0	1	1	2	2	0	0
49	0	0	0	0	0	1	0	1	0
50	0	1	0	0	0	0	0	0	1
51	0	0	0	0	0	0	1	0	0
52	0	0	0	0	0	1	0	0	0
Totals	1	1	3	1	1	5	4	3	1

Table 1. Continued

Length 1-inch interval	Age (years) 47	48	49	50	54	55	57	64	Totals
8	0	0	0	0	0	0	0	0	1
9	0	0	0	0	0	0	0	0	3
20	0	0	0	0	0	0	0	0	1
22	0	0	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	1
31	0	0	0	0	0	0	0	0	1
32	0	0	0	0	0	0	0	0	1
36	0	0	0	0	0	0	0	0	1
39	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	0	0	1
44	0	0	0	0	0	0	0	0	1
45	1	0	0	0	0	0	0	0	5
46	1	0	0	0	0	1	0	0	6
47	0	0	0	1	0	0	0	0	4
48	1	0	0	0	1	0	0	0	8
49	1	2	1	0	0	0	1	0	7
50	0	0	0	0	0	0	0	0	2
51	0	0	0	0	0	0	0	1	2
52	0	0	0	0	0	0	0	0	1
Totals	4	2	1	1	1	1	1	1	48

Table 2. The Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for black drum sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years)								
	0	2	3	6	12	16	24	31	32
8	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
9	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
42	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
45	0.000	0.000	0.000	0.000	0.000	0.200	0.000	0.000	0.000
46	0.000	0.000	0.000	0.000	0.167	0.000	0.000	0.167	0.000
47	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250
48	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

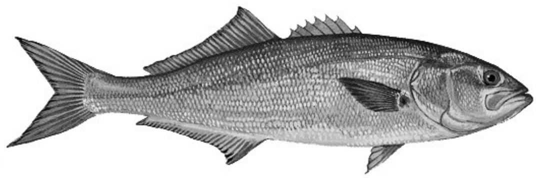
Table 2. Continued

Length 1-inch interval	Age (years) 34	35	39	40	41	42	43	44	45
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.200	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.000
46	0.000	0.000	0.000	0.000	0.000	0.167	0.000	0.167	0.000
47	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000
48	0.000	0.000	0.000	0.125	0.125	0.250	0.250	0.000	0.000
49	0.000	0.000	0.000	0.000	0.000	0.143	0.000	0.143	0.000
50	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.500
51	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.000
52	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000

Table 2. Continued

Length 1-inch interval	Age (years) 47	48	49	50	54	55	57	64
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
32	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
46	0.167	0.000	0.000	0.000	0.000	0.167	0.000	0.000
47	0.000	0.000	0.000	0.250	0.000	0.000	0.000	0.000
48	0.125	0.000	0.000	0.000	0.125	0.000	0.000	0.000
49	0.143	0.286	0.143	0.000	0.000	0.000	0.143	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500
52	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Chapter 3
Bluefish



Pomatomus saltatrix

INTRODUCTION

We aged a total of 374 bluefish, *Pomatomus saltatrix*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The bluefish ages ranged from 0 to 11 with an average age of 2.2, a standard deviation of 1.72, and a standard error of 0.09. Eleven age classes (0 to 9 and 11) were represented, comprising fish from the 1996, 1998 to 2007 year-classes. The 2005 and 2006 year-classes dominated the sample.

METHODS

Sample size for ageing — We estimated sample size for ageing bluefish in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing bluefish in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of bluefish collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of bluefish used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish that are aged, the smaller the CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored dry in their original VMRC coin envelopes.

Preparation — We used a thin-section and bake technique to process bluefish otoliths for age determination. Otolith preparation began by randomly selecting either the right or left otolith. Each otolith was mounted with Crystal Bond onto a standard microscope slide with its distal surface orientated upwards. Once mounted, a small mark was placed on the otolith surface directly above the otolith focus. The slide, with attached otolith, was then secured to a Buehler Isomet low-speed saw equipped with two, three-inch Norton diamond-wheel wafering blades separated by a 0.4 mm spacer, which was slightly smaller in diameter than the diamond blades. The otolith was positioned so that the wafering blades straddled each side of the otolith focus ink mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the otolith section was placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was otolith size dependent and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 dissecting microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 1). If an otolith was properly sectioned the sulcal groove came to a sharp point within the middle of the focus. Typically the first year's annulus was found by locating the focus of the otolith, which was characterized as a visually distinct dark oblong region found in the center of the otolith. The first year's annulus had the highest visibility proximal to the focus along the edge of the sulcal groove. Once located, the first year's annulus was followed outward from the sulcal groove towards the dorsal perimeter of the otolith. Often, but not always, the first year was associated with a very distinct crenellation on the dorsal surface and a prominent protrusion on the ventral surface. Unfortunately both these landmarks had a tendency to become less prominent in older fish.

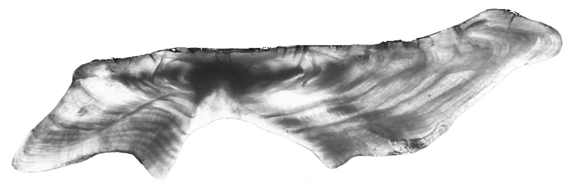


Figure 1. Otolith thin-section from a 850mm TL 8 year-old female bluefish.

Even with the bake and thin-section technique, interpretation of the growth zones from the otoliths of young bluefish was difficult. Rapid growth within the first year of life prevents a sharp delineation between opaque and translucent zones. When the exact location of the first year was not clearly evident, and the otolith had been sectioned accurately, a combination of surface landscape (1st year crenellation) and the position of the second annuli were used to help determine the position of the first annulus.

What appeared to be "double annuli" were occasionally observed in bluefish 4-7years of age and older. This double-annulus formation was typically characterized by distinct and separate annuli in extremely close proximity to each other. We do not know if the formation of these double annuli were two separate annuli, or in fact only one, but they seemed to occur during times of reduced growth after maturation. "Double annuli" were considered to be one annulus when both marks joined to form a central origin. The origin being the sulcal groove and at the outer peripheral edge of the otolith. If these annuli did not meet to form a central origin they were considered two distinct annuli, and were counted as such.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995). Also, to detect any changes or drift in our ageing methods, both readers re-aged the otoliths of 50 randomly selected fish previously aged in 2000.

RESULTS

We estimated a sample size of 341 for ageing bluefish in 2007, ranging in length interval from 7 to 36 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 6% for age 2 and the largest CV of 25% for age 0 fish. In 2007, we randomly selected and aged 374 fish from the 443 bluefish collected by VMRC. We were short of 50 fish compared to the optimum ageing sample size. Because those fish mainly fell within the very large and small length intervals (Table 1), the precision for the estimates of major age groups would not be influenced significantly. The otoliths of one fish in the 30-inch length interval were lost during fish processing.

The measurement of reader self-precision was good for Reader 1 (CV = 3.8%) and was low for Reader 2 (CV = 15.1%). There was evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 59$, df = 16, $P < 0.0001$). Figure 2 illustrates the between readers' precision of age estimates. The average coefficient of variation (CV) of 15.7% was high compared to the CV of 8.3% in 2006. The between-reader agreement for otoliths for one year or less was 94% of all aged fish. Such a high agreement between the readers and the large CVs were partially due to the sample dominated by younger fish.

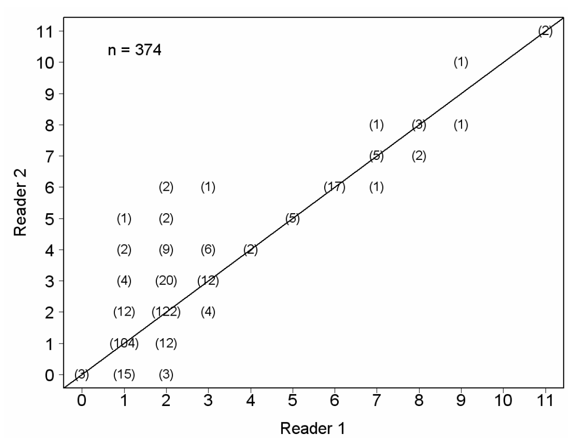


Figure 2. Between-readers comparison of otolith age estimates for bluefish in 2007

Of the 374 fish aged with otoliths 11 age classes were represented (Table 2). The average age for the sample was 2.2 years, and the standard deviation and standard error were 1.72 and 0.09, respectively.

Year-class data (Figure 3) indicates that recruitment into the fishery began at age 0, which corresponded to the 2007 year-class for bluefish caught in 2007. One and 2-year-old fish were the dominant year-classes in the 2007 sample.

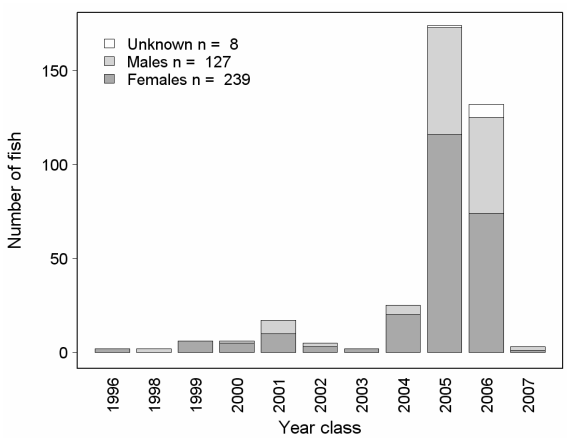


Figure 3. Year-class frequency distribution for bluefish collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex fish were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

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Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

S-Plus. 1999. S-Plus 4.5 Guide to Statistics. Data Analysis Products Division. Math Soft, Inc. Seattle, Washington

List of Tables

Table 1. Number of bluefish collected, and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Length 1-inch interval	Target	Collected	Aged	Need
7	5	0	0	5
8	5	1	1	4
9	5	26	10	0
10	5	17	6	0
11	9	25	20	0
12	22	35	26	0
13	27	34	32	0
14	32	38	35	0
15	33	45	40	0
16	27	45	40	0
17	28	35	28	0
18	22	31	28	0
19	11	24	22	0
20	11	11	11	0
21	6	10	10	0
22	5	7	7	0
23	5	5	5	0
24	5	6	6	0
25	5	8	8	0
26	5	0	0	5
27	4	1	1	3
28	8	3	3	5
29	10	3	3	7
30	11	8	7	4
31	9	14	14	0
32	6	8	8	0
33	5	1	1	4
34	5	1	1	4
35	5	1	1	4
36	5	0	0	5
Totals	341	443	374	50

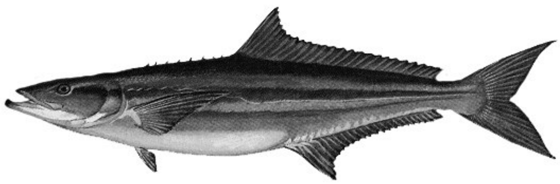
Table 2. The number of bluefish assigned to each total length-at-age category for 374 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	7	8	9	11	Totals
8	0	0	1	0	0	0	0	0	0	0	0	1
9	2	7	1	0	0	0	0	0	0	0	0	10
10	0	6	0	0	0	0	0	0	0	0	0	6
11	0	19	1	0	0	0	0	0	0	0	0	20
12	1	23	2	0	0	0	0	0	0	0	0	26
13	0	26	6	0	0	0	0	0	0	0	0	32
14	0	30	4	1	0	0	0	0	0	0	0	35
15	0	14	24	2	0	0	0	0	0	0	0	40
16	0	1	31	6	2	0	0	0	0	0	0	40
17	0	1	22	5	0	0	0	0	0	0	0	28
18	0	0	22	6	0	0	0	0	0	0	0	28
19	0	0	19	3	0	0	0	0	0	0	0	22
20	0	2	8	1	0	0	0	0	0	0	0	11
21	0	1	8	1	0	0	0	0	0	0	0	10
22	0	1	6	0	0	0	0	0	0	0	0	7
23	0	1	4	0	0	0	0	0	0	0	0	5
24	0	0	6	0	0	0	0	0	0	0	0	6
25	0	0	8	0	0	0	0	0	0	0	0	8
27	0	0	0	0	0	0	1	0	0	0	0	1
28	0	0	0	0	0	1	1	1	0	0	0	3
29	0	0	1	0	0	2	0	0	0	0	0	3
30	0	0	0	0	0	0	4	1	2	0	0	7
31	0	0	0	0	0	1	8	2	2	1	0	14
32	0	0	0	0	0	1	2	2	1	1	1	8
33	0	0	0	0	0	0	1	0	0	0	0	1
34	0	0	0	0	0	0	0	0	0	0	1	1
35	0	0	0	0	0	0	0	0	1	0	0	1
Totals	3	132	174	25	2	5	17	6	6	2	2	374

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for bluefish sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years)										
	0	1	2	3	4	5	6	7	8	9	11
8	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.200	0.700	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.950	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.038	0.885	0.077	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.812	0.188	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.857	0.114	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.350	0.600	0.050	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.025	0.775	0.150	0.050	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.036	0.786	0.179	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.786	0.214	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.864	0.136	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.182	0.727	0.091	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.100	0.800	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.000	0.143	0.857	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.200	0.800	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	0.333	0.333	0.333	0.000	0.000	0.000
29	0.000	0.000	0.333	0.000	0.000	0.667	0.000	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.571	0.143	0.286	0.000	0.000
31	0.000	0.000	0.000	0.000	0.000	0.071	0.571	0.143	0.143	0.071	0.000
32	0.000	0.000	0.000	0.000	0.000	0.125	0.250	0.250	0.125	0.125	0.125
33	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
34	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
35	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000

Chapter 4
Cobia



Rachycentron canadum

INTRODUCTION

A total of 62 cobia, *Rachycentron canadum*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The average age of the sample was 5.6 years, and the standard deviation and standard error were 2.6 and 0.33, respectively. Thirteen age classes (1 to 12 and 14) were represented, comprising fish from the 1993, 1995 through 2006 year-classes. The 2002 and 2004 year-class dominated the sample.

METHODS

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored in their original VMRC coin envelopes.

Preparation — Individual otoliths were placed into 14 mm x 5 mm x 3 mm wells (Ladd Industries silicon rubber mold) filled with Loctite adhesive. Each otolith was rolled around in the Loctite to remove all trapped air bubbles and ensure complete coverage of the otolith surface. The otoliths were oriented sulcal side down with the long axis of the otolith exactly parallel with the long axis of the mold well. Once the otoliths were properly oriented, the mold was placed under UV light and left to solidify overnight. Once dry, each embedded otolith was removed from the mold and mounted with Crystal Bond onto a standard microscope slide. Once mounted, a small mark was placed on the otolith surface directly above the otolith focus, which was located using a microscope under transmitted light. The slide, with attached otolith, was then secured to an Isomet saw equipped with two diamond wafering blades separated by a 0.4 mm spacer, which was slightly smaller in diameter than the diamond blades. The otolith was positioned so that the wafering blades straddled each side of the focus ink mark. The glass slide was adjusted to ensure that the blades were exactly perpendicular to the long axis of the otolith. The otolith wafer section was viewed under a dissecting microscope to determine which side (cut surface) of the otolith was closer to the focus. The otolith section was mounted best-side up onto a glass slide with Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — All otolith sections were aged by Two different readers using a Leica MZ-12 dissecting microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification aged all sectioned otoliths (Figure 1).

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

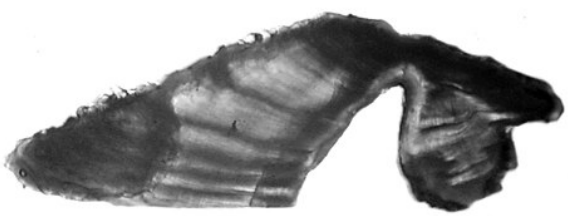


Figure 1. Otolith thin-section from a 1524 mm TL 6 year old cobia.

Comparison Tests — Readers 1 and 2 aged all fish for a second time to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

The measurement of reader self-precision was high for both readers (Reader 1's CV = 1.8% and Reader 2's CV = 1.5%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 4.33$, df = 6, $P = 0.6317$). Figure 2 illustrates the between readers' precision of age estimates. The average coefficient of variation (CV) of 2.5% was not significant with an agreement of 82% between two readers.

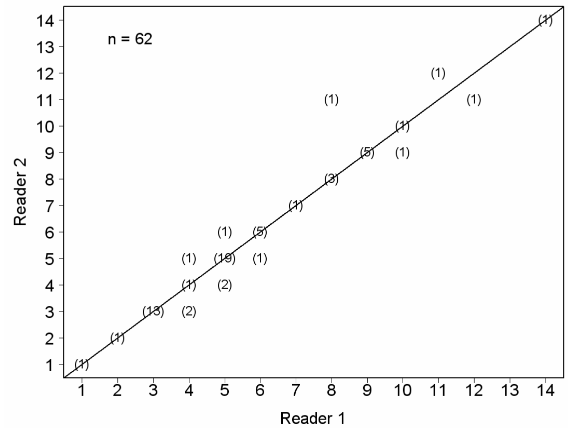


Figure 2. Between-reader comparison of otolith age estimates for cobia in 2007.

Of the 62 fish aged, 13 age classes were represented (Table 1). The average age of the sample was 5.6 years, and the standard deviation and standard error were 2.6 and 0.33, respectively.

Year-class data (Figure 3) indicates that recruitment into the fishery begins at age 1, which corresponds to the 2006 year-class for cobia caught in 2007. The year-class 2002 and 2004 dominated the sample.

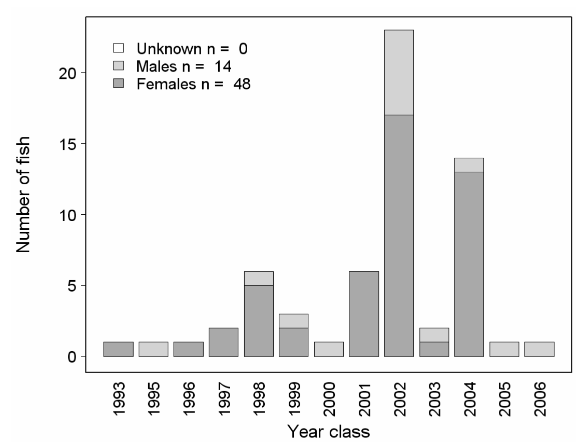


Figure 3. Year-class frequency distribution for cobia collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex fish were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 2 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Franks, J.S., J.R. Warren, and M.V. Buchanan. 1999. Age and growth of cobia, Rachycentron canadum, from the northeastern Gulf of Mexico. Fish. Bull. 97:459-471.

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Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

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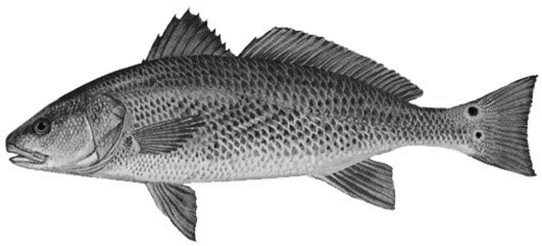
Table 1. The number of cobia assigned to each total length-at-age category for 62 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 1	2	3	4	5	6	7	8	9	10	11	12	14	Totals
24	1	0	0	0	0	0	0	0	0	0	0	0	0	1
37	0	1	0	1	0	0	0	0	0	0	0	0	0	2
38	0	0	2	0	0	0	0	0	0	0	0	0	0	2
39	0	0	2	0	1	0	0	0	0	0	0	0	0	3
40	0	0	3	0	1	0	0	0	0	0	0	0	0	4
41	0	0	1	1	0	0	0	0	0	0	0	0	0	2
42	0	0	1	0	3	0	0	0	0	0	0	0	0	4
43	0	0	2	0	1	0	0	0	0	0	0	0	0	3
44	0	0	1	0	1	0	0	0	0	0	0	0	0	2
45	0	0	1	0	0	0	0	1	0	0	0	0	0	2
46	0	0	0	0	3	0	1	0	0	0	0	0	0	4
47	0	0	0	0	1	0	0	0	0	0	0	0	0	1
48	0	0	0	0	1	1	0	0	0	0	0	0	0	2
49	0	0	0	0	1	1	0	0	0	0	0	0	0	2
50	0	0	0	0	4	1	0	0	0	0	0	0	0	5
51	0	0	1	0	3	1	0	0	3	0	0	0	1	9
52	0	0	0	0	1	1	0	0	0	0	0	0	0	2
53	0	0	0	0	1	0	0	0	0	0	0	1	0	2
55	0	0	0	0	0	0	0	0	1	0	0	0	0	1
56	0	0	0	0	0	0	0	0	1	0	0	0	0	1
57	0	0	0	0	0	1	0	1	0	0	0	0	0	2
59	0	0	0	0	1	0	0	0	1	0	0	0	0	2
60	0	0	0	0	0	0	0	1	0	2	1	0	0	4
Totals	1	1	14	2	23	6	1	3	6	2	1	1	1	62

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for cobia sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years)												
	1	2	3	4	5	6	7	8	9	10	11	12	14
24	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
37	0.000	0.500	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
38	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
39	0.000	0.000	0.667	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
40	0.000	0.000	0.750	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	0.000	0.000	0.250	0.000	0.750	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
43	0.000	0.000	0.667	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.500	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000
46	0.000	0.000	0.000	0.000	0.750	0.000	0.250	0.000	0.000	0.000	0.000	0.000	0.000
47	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
48	0.000	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
49	0.000	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.800	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
51	0.000	0.000	0.111	0.000	0.333	0.111	0.000	0.000	0.333	0.000	0.000	0.000	0.111
52	0.000	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
53	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000
55	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
56	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
57	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.500	0.000	0.000	0.000	0.000	0.000
59	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000
60	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.000	0.500	0.250	0.000	0.000

Chapter 5
Red Drum



Sciaenops ocellatus

INTRODUCTION

A total of 101 red drum, *Sciaenops ocellatus*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The average age of the sample was 2 years, and the standard deviation and standard error were 0.32 and 0.03, respectively. Three age classes (1, 2 and 3) were represented, comprising fish from the 2004, 2005, and 2006 year-classes. One-year-old fish were the dominant year-class in the 2007 sample.

METHODS

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored dry in their original labeled coin envelopes.

Preparation — Otoliths were processed for ageing following the methods described in Bobko (1991) for black drum. Briefly, otoliths were mounted on glass slides with Crystal Bond. At least one transverse cross-section was cut through the nucleus of each otolith with a Buehler Isomet low-speed saw equipped with two three inch, fine grit Norton diamond-wafering blades separated by a 0.3mm steels spacer. After drying, a thin layer of Flo-texx mounting medium was applied to the otolith sections to increase light transmission through the translucent zones, which provided enhanced contrast and greater readability.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 dissecting microscope with transmitted light and dark-field polarization at between 8 and 20 times magnification (Figure 1).

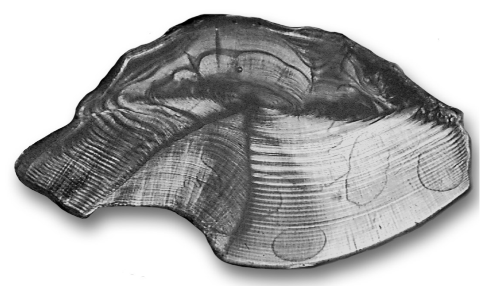


Figure 1. Otolith thin-section from 26 year old red drum.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Red drum ages were based on a biological birthdate of September 1, while year-class assignment was based on a January 1 annual birthdate. Red drum were treated in this manner because of the timing of spawning and the fact that the first annulus is not seen on an otolith until a fish's second spring. For example, a red drum that was born in September of 1997 and captured in March of 1999 would not have any visible annuli on its otoliths, but would be aged as a 1 year-old fish since it lived beyond one September (September 1998). But this 1 year-old fish caught in 1999 would be mistakenly assigned to the 1998 year-class. To properly assign the fish to its correct year-class, 1997, a January birthdate was used which would make the fish 2 years-old (since the fish lived past January 1998 and 1999) and year-class would be assigned correctly.

Comparison Tests — Readers 1 and 2 aged all fish for a second time to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

Measurements of reader self-precision were very high, with both readers able to reproduce 100 % of the ages of previously read otoliths (CV = 0). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 1$, df = 1, $P = 0.3173$). Figure 2 illustrates the between readers' precision of age estimates. The average coefficient of variation (CV) of 0.5% was not significant with an agreement of 99% between two readers.

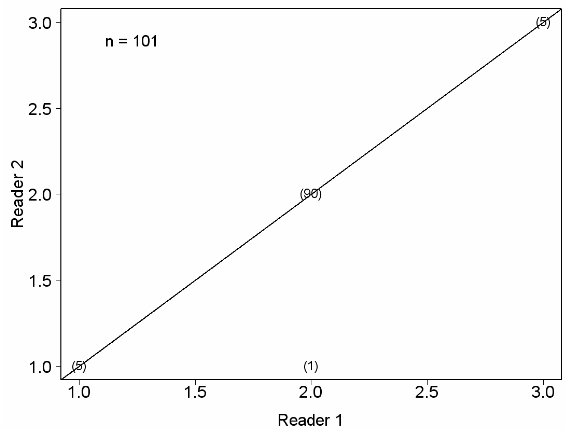


Figure 2. Between-reader comparison of otolith age estimates for red drum in 2007.

Of the 101 fish aged with otoliths, 3 age classes were represented (Table 1). The average age of the sample was 2 years, and the standard deviation and standard error were 0.32 and 0.03, respectively.

Year-class data (Figure 3) indicate that the 2005 year-class dominated the sample. Indicative of the trend in the recreational fishing, very few older fish were collected in 2007.

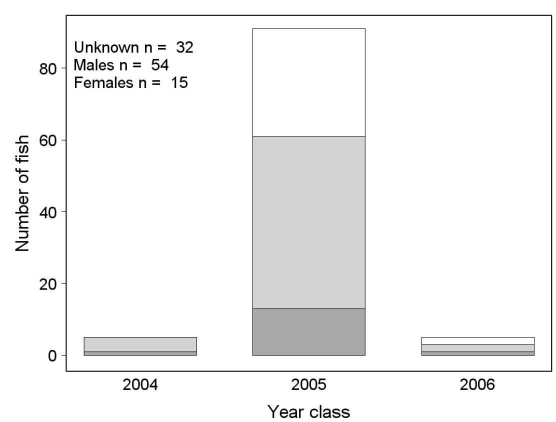


Figure 3. Year-class frequency distribution for red drum collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex fish were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 2 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

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Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

S-Plus. 1999. S-Plus 4.5 Guide to Statistics. Data Analysis Products Division. Math Soft, Inc. Seattle, Washington.

List of Tables

Table 1. The number of red drum assigned to each total length-at-age category for the 48 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 1	2	3	Totals
15	0	1	0	1
17	0	2	0	2
18	3	13	0	16
19	2	16	1	19
20	0	14	0	14
21	0	12	0	12
22	0	8	0	8
23	0	8	0	8
24	0	7	1	8
25	0	9	2	11
26	0	1	1	2
Totals	5	91	5	101

Table 2. Age-Length key, as propostion-at-age in each 1-inch length interval, based on otolith ages for red drum sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years)		
	1	2	3
15	0.000	1.000	0.000
17	0.000	1.000	0.000
18	0.188	0.812	0.000
19	0.105	0.842	0.053
20	0.000	1.000	0.000
21	0.000	1.000	0.000
22	0.000	1.000	0.000
23	0.000	1.000	0.000
24	0.000	0.875	0.125
25	0.000	0.818	0.182
26	0.000	0.500	0.500

Chapter 6
Atlantic Spadefish

Chaetodipterus faber

INTRODUCTION

We aged a total of 292 spadefish, *Chaetodipterus faber*, collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. The spadefish ages ranged from 0 to 17 with an average age of 2.9, a standard deviation of 1.73, and a standard error of 0.1. Ten age classes (0 to 7 and 16 to 11) were represented, comprising fish from the 1990 to 1991, 2000 to 2007 year-classes. The 2002, 2004, and 2005 year-class dominated the sample.

METHODS

Sample size for ageing — We estimated sample size for ageing spadefish in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spadefish in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spadefish collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spadefish used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which ther is only a 1% reduction in CV achieved by aging additional 100 or more fish.

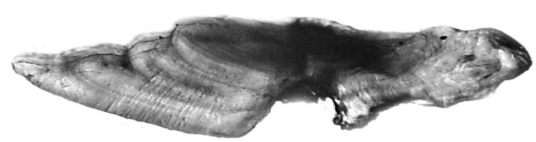

Figure 1. Sectioned otolith from a 3-year-old female spadefish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth

Laboratory sample numbers. All otoliths were stored dry in labeled cell well trays.

Preparation — Small otoliths were processed for ageing using a bake and thin-section technique. Preparation began by randomly selecting either the right or left otolith from each fish.. The whole otoliths were placed in a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was otolith size dependent and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked otoliths were individually placed into 14mm x 5mm x 3mm wells (Ladd Industries silicone rubber mold) filled with Loctite 349 photo-active adhesive. The mold was placed under ultraviolet light to cure and harden the Loctite for 24 hours. After the 24 hour curing period, the embedded small spadefish otoliths could be removed from the silicone mold and processed along with the larger spadefish otoliths. Large spadefish otoliths were mounted directly with Crystal Bond onto a standard microscope slide with its distal surface orientated upwards. Once mounted, a small mark was placed on the otolith surface directly above the otolith focus, which was identified under a stereomicroscope in transmitted light. The slide, with attached otolith, was then secured to a Buehler Isomet low-speed saw equipped with two fine grit Norton diamond-wafering blades separated by a 0.4 mm steel spacer. The otolith was positioned so that the wafering blades straddled each side of the otolith focus ink mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the large otolith sections were placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C until achieving the light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections. Small otolith sections of quality were mounted with Flo-texx directly.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 1).

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within- reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995). Also, to detect any changes or drift in our ageing methods, both readers re-aged the otoliths of 50 randomly selected fish previously aged in 2003.

RESULTS

We estimated a sample size of 336 for ageing bluefish in 2007, ranging in length interval from 3 to 24 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 2 and the largest CV of 21% for age 5 fish. In 2007, we randomly selected and aged 292 fish from 368 bluefish collected by VMRC. We were short of 75 fish compared to the optimum ageing sample size. Because those fish mainly fell within the second mode of spadefish length distribution (around the 20-inch length interval) (Table 1), the precision for the estimates of older age groups would be influenced significantly.

Measurements of reader self-precision were fair (Reader 1's CV = 5.2% and Reader 2's CV = 3.2%). Figure 2 illustrates the between readers' precision of age estimates. There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 16$, df = 15, P = 0.3821). The average coefficient of variation (CV) of 5.6% was marginal with an agreement of 80% between two readers.

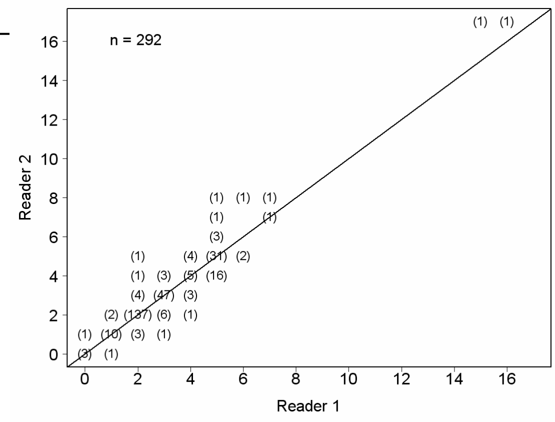

Figure 2. Between-reader comparison of otolith age estimates for spadefish in 2007.

Of the 292 fish aged with otoliths, 10 age classes were represented (Table 2). The average age of the sample was 2.9 years, and the standard deviation and standard error were 1.73 and 0.10, respectively. Year-class data (Figure 3) indicate that the 2002, 2004, and 2005 year-classes dominated the sample.

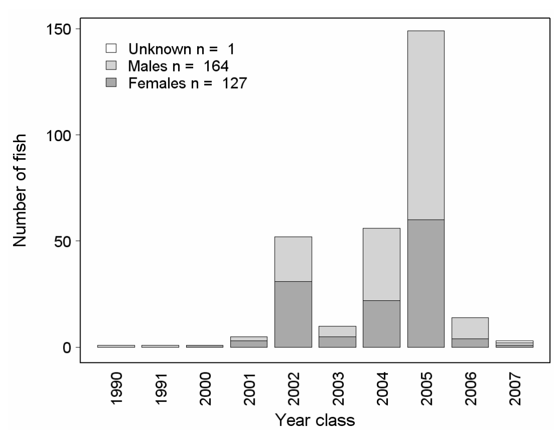

Figure 3. Year-class frequency distribution for spadefish collected for ageing in 2007.

Distribution is broken down by sex. "Unknown" sex fish were either jubeniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

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List of Tables

Table 1. Number of spadefish collected, and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
3	5	3	3	2
4	5	0	0	5
5	8	5	4	4
6	36	49	36	0
7	50	60	50	0
8	42	57	42	0
9	25	39	27	0
10	14	23	15	0
11	10	15	14	0
12	7	18	14	0
13	8	16	14	0
14	7	9	9	0
15	11	7	7	4
16	10	16	13	0
17	10	16	14	0
18	11	18	13	0
19	17	9	9	8
20	24	4	4	20
21	15	3	3	12
22	11	0	0	11
23	5	1	1	4
24	5	0	0	5
Totals	336	368	292	75

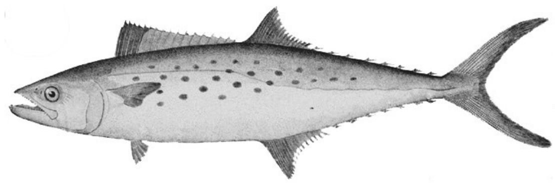
Table 2. The number of spadefish assigned to each total length-at-age category for 292 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	7	16	17	Totals
3	1	1	1	0	0	0	0	0	0	0	3
5	0	3	1	0	0	0	0	0	0	0	4
6	1	9	26	0	0	0	0	0	0	0	36
7	1	0	48	1	0	0	0	0	0	0	50
8	0	0	35	6	0	1	0	0	0	0	42
9	0	1	22	4	0	0	0	0	0	0	27
10	0	0	7	8	0	0	0	0	0	0	15
11	0	0	3	10	1	0	0	0	0	0	14
12	0	0	4	8	0	1	1	0	0	0	14
13	0	0	1	12	0	1	0	0	0	0	14
14	0	0	0	6	0	3	0	0	0	0	9
15	0	0	0	0	2	4	1	0	0	0	7
16	0	0	0	0	1	11	1	0	0	0	13
17	0	0	0	0	3	11	0	0	0	0	14
18	0	0	1	0	3	9	0	0	0	0	13
19	0	0	0	0	0	7	1	1	0	0	9
20	0	0	0	0	0	3	1	0	0	0	4
21	0	0	0	1	0	1	0	0	1	0	3
23	0	0	0	0	0	0	0	0	0	1	1
Totals	3	14	149	56	10	52	5	1	1	1	292

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for spadefish sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	7	16	17
3	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.750	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.028	0.250	0.722	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.020	0.000	0.960	0.020	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.833	0.143	0.000	0.024	0.000	0.000	0.000	0.000
9	0.000	0.037	0.815	0.148	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.467	0.533	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.214	0.714	0.071	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.286	0.571	0.000	0.071	0.071	0.000	0.000	0.000
13	0.000	0.000	0.071	0.857	0.000	0.071	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.667	0.000	0.333	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.286	0.571	0.143	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.077	0.846	0.077	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.214	0.786	0.000	0.000	0.000	0.000
18	0.000	0.000	0.077	0.000	0.231	0.692	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.778	0.111	0.111	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.750	0.250	0.000	0.000	0.000
21	0.000	0.000	0.000	0.333	0.000	0.333	0.000	0.000	0.333	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Chapter 7
Spanish Mackerel



Scomberomorous maculatus

INTRODUCTION

We aged a total of 250 Spanish mackerel, *Scomberomorous maculatus*, collected by the Virginia Marine Resource Commission (VMRC) Biological Sampling Program in 2007. The Spanish mackerel ages ranged from 0 to 5 with an average age of 1.3 years, and the standard deviation and standard error were 1.32 and 0.08, respectively. Eight age classes were observed (0 to 6, and 8), representing fish from the 1999, 2001 through 2007 year-classes. The 2006 year-class dominated the sample.

METHODS

Sample size for ageing — We estimated sample size for ageing Spanish mackerel in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

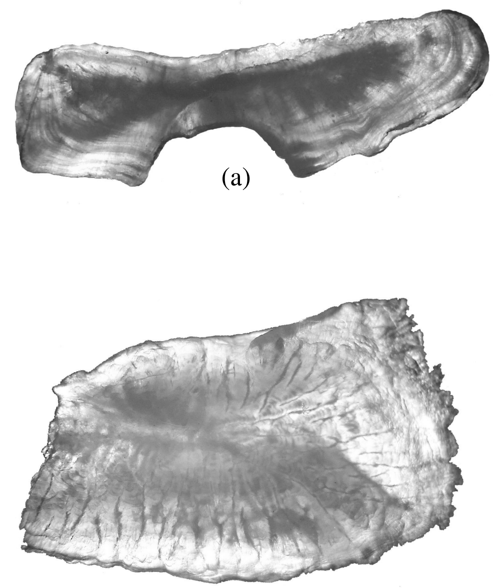
where A is the sample size for ageing Spanish mackerel in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of Spanish mackerel collected from 2001 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of Spanish mackerel used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% reduction in CV achieved by aging an additional 100 or more fish.

Handling of collection — All otoliths and associated data were transferred to the Center for Quantitative Fisheries Ecology's Age and Growth Laboratory as they were collected. In the lab they were sorted by date of capture, their envelope labels verified against VMRC's collection data, and each fish was assigned a unique Age and Growth Laboratory sample number. All otoliths were stored dry in their original VMRC coin envelopes.

Preparation — Otoliths from fish were processed using an Age and Growth Laboratory thin section technique modified to deal with the fragile nature of Spanish mackerel otoliths. Briefly, an otolith was first embedded in 14mm x 5mm x 3mm wells with Loctite 349 photo-active adhesive. The mold was placed

under ultraviolet light to cure and harden the Loctite. The embedded otolith was removed from the
Silicon mold and the location of the core of the otolith was then marked with an extra fine point permanent marker. A thin transverse section was made using a Buehler Isomet saw equipped with two fine-grit Norton diamond-wheel wafering blades separated by a 0.3 mm steel spacer. The otolith section was mounted best-side up onto a glass slide with a thin layer of Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — By convention, a birth date of January 1 is assigned to all Northern Hemisphere fish species. We use a system of age determination that assigns age class according to the date of sacrifice with respect to this international accepted birth date and the timing of annulus formation. Although an otolith annulus is actually the combination of an opaque and translucent band, when ageing otoliths we actually enumerate only the opaque bands, but still refer to them as annuli. Spanish mackerel otolith annulus formation occurs between the months of April and June, with younger fish tending to lay down annuli earlier than older fish. Fish age is written first followed by the actual number of annuli visible listed within parentheses (e.g., 3(3)). The presence of a "+" after the number in the parentheses indicates new growth, or "plus growth" visible on the structure's margin. Using this method, a fish sacrificed in January before annulus formation with three visible annuli would be assigned the same age, 4(3+), as a fish with four visible annuli sacrificed in August after annulus formation, 4(4+). Year-class is then assigned once the reader determines the fish's age and takes into account the year of capture.



(a)

(b)

Figure 1. A three year old spanish mackerel otolith from a 0.6 kg male a) thin-section b) whole otolith with part of the tip broken off.

Two different readers aged all sectioned otoliths using a Leica MZ-12 stereo microscope with polarized transmitted light at between 8 and 40 times magnification. The first annulus on sectioned otoliths was often quite distant from the core, with subsequent annuli regularly spaced along the sulcal groove out towards the proximal (inner-face) edge of the otolith (Figures 1 and 2).

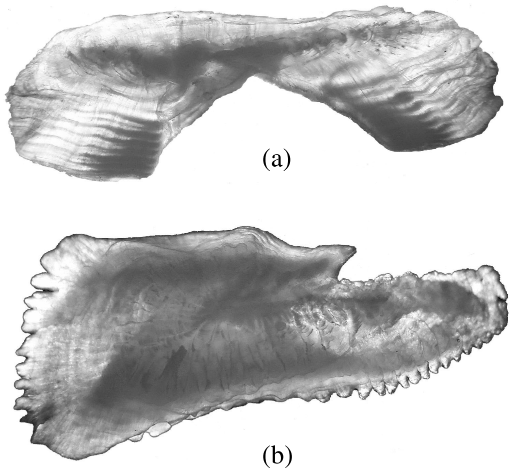


Figure 2. An eight year old Spanish mackerel otolith from a 1 kg female a) thin-section b) whole otolith.

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 336 for ageing Spanish mackerel in 2007, ranging in length interval from 7 to 31 inches (Table 1). This sample size provided a range in CV for age composition approximately from the CV much smaller than 5% for age 1 and the largest CV of 18% for age 4 fish. In 2007, we randomly selected and aged 250 fish from 261 Spanish mackerel collected by VMRC. We were short of 109 fish compared to the optimum ageing sample size. Because those fish mainly fell within the peak of Spanish mackerel length distribution (around the 16-inch length interval (Table 1), the precision for the estimates of older age groups would be influenced significantly while the precision for age 1 was still high with the CV lower than 5%.

The measurement of reader self-precision was good (Reader 1's CV = 1.9% and Reader 2's CV = 2.7%). Figure 3 illustrates the between readers' precision of age estimates. There was no evidence of systematic disagreement between reader 1 and reader 2 (test of symmetry: $\chi^2 = 3.67$, df = 3, $P = 0.2998$). The average between-reader coefficient of variation (CV) of 3.4% was good with an agreement of 94% between two readers.

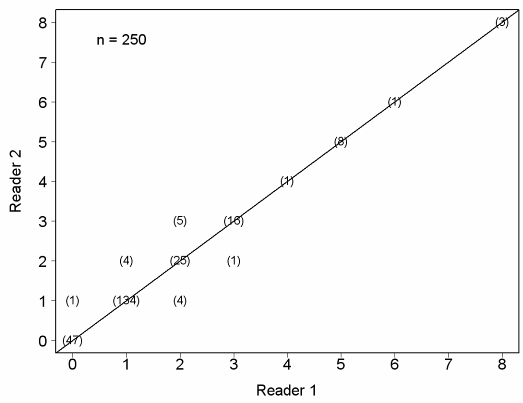


Figure 3. Between-reader comparison of otolith age estimates for Spanish mackerel in 2007.

Of the 250 Spanish mackerel aged with otoliths, 8 age classes were represented (Table 2). The average age was 1.3 year old, and the standard deviation and standard error were 1.32 and 0.08, respectively. Year-class data (Figure 4) show that the fishery was comprised of 8 year-classes, comprising fish from the 1999, 2001 through 2007 year-classes, with fish primarily from the 2006 year-classes.

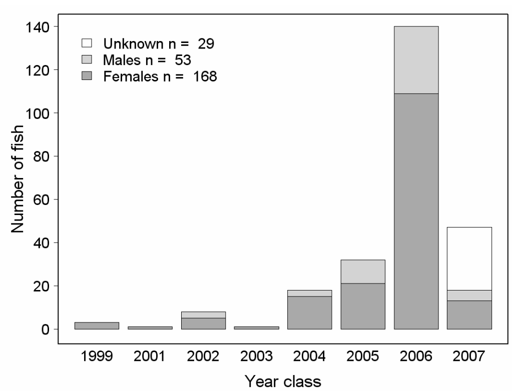


Figure 4. Year-class frequency distribution for Spanish mackerel collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for etermining the consistency of age terminations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analyzing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

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List of Tables

Table 1. Number of Spanish mackerel collected and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7	5	0	0	5
8	5	1	1	4
9	5	7	7	0
10	5	6	5	0
11	5	16	14	0
12	5	16	12	0
13	10	3	3	7
14	18	17	17	1
15	49	36	34	15
16	59	31	31	28
17	44	34	33	11
18	25	24	23	2
19	22	15	15	7
20	20	15	15	5
21	12	11	11	1
22	8	10	10	0
23	4	6	6	0
24	5	1	1	4
25	5	3	3	2
26	5	1	1	4
27	5	3	3	2
28	5	1	1	4
29	5	2	2	3
30	5	1	1	4
31	0	1	1	0
Totals	336	261	250	109

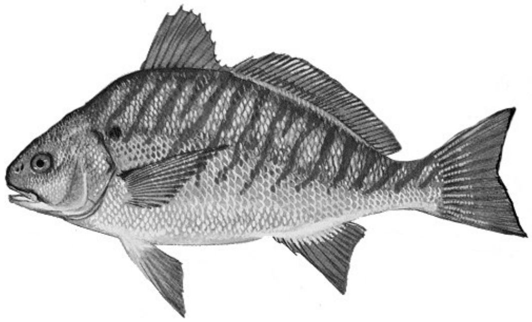
Table 2. The number of Spanish mackerel assigned to each total length-at-age category for 250 fish sampled for otolith age determination in Virginia during 2007

Length 1-inch interval	Age (years)								
	0	1	2	3	4	5	6	8	Totals
8	1	0	0	0	0	0	0	0	1
9	7	0	0	0	0	0	0	0	7
10	5	0	0	0	0	0	0	0	5
11	14	0	0	0	0	0	0	0	14
12	12	0	0	0	0	0	0	0	12
13	1	2	0	0	0	0	0	0	3
14	4	13	0	0	0	0	0	0	17
15	0	34	0	0	0	0	0	0	34
16	3	27	1	0	0	0	0	0	31
17	0	31	2	0	0	0	0	0	33
18	0	20	3	0	0	0	0	0	23
19	0	10	5	0	0	0	0	0	15
20	0	2	11	1	0	1	0	0	15
21	0	1	5	3	0	2	0	0	11
22	0	0	3	7	0	0	0	0	10
23	0	0	2	4	0	0	0	0	6
24	0	0	0	1	0	0	0	0	1
25	0	0	0	1	0	1	1	0	3
26	0	0	0	0	0	1	0	0	1
27	0	0	0	1	0	2	0	0	3
28	0	0	0	0	1	0	0	0	1
29	0	0	0	0	0	1	0	1	2
30	0	0	0	0	0	0	0	1	1
31	0	0	0	0	0	0	0	1	1
Totals	47	140	32	18	1	8	1	3	250

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for Spanish mackerel sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	8
8	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.333	0.667	0.000	0.000	0.000	0.000	0.000	0.000
14	0.235	0.765	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.097	0.871	0.032	0.000	0.000	0.000	0.000	0.000
17	0.000	0.939	0.061	0.000	0.000	0.000	0.000	0.000
18	0.000	0.870	0.130	0.000	0.000	0.000	0.000	0.000
19	0.000	0.667	0.333	0.000	0.000	0.000	0.000	0.000
20	0.000	0.133	0.733	0.067	0.000	0.067	0.000	0.000
21	0.000	0.091	0.455	0.273	0.000	0.182	0.000	0.000
22	0.000	0.000	0.300	0.700	0.000	0.000	0.000	0.000
23	0.000	0.000	0.333	0.667	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.333	0.000	0.333	0.333	0.000
26	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
27	0.000	0.000	0.000	0.333	0.000	0.667	0.000	0.000
28	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.500
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
31	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Chapter 8
Spot



Leiostomus xanthurus

INTRODUCTION

We aged a total of 246 spot, *Leiostomus xanthurus*, collected by the VMRC's Biological Sampling Program in 2007. The spot ages ranged from 0 to 5 with an average age of 1.6 years, a standard deviation of 0.7, and a standard error of 0.04. Six age classes (0 to 5) were represented, comprising fish from the 2002 through 2007 year-classes, with fish predominantly from the 2005 and 2006 year-class.

METHODS

Sample size for ageing — We estimated sample size for ageing spot in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spot in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spot collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spot used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only 1% CV reduction achieved by aging an additional 100 or more fish.

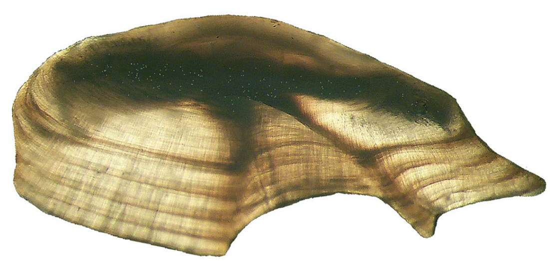


Figure 1. Sectioned otolith from a 5 year old spot.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored in their original VMRC coin envelopes.

Preparation — Otoliths were processed following the methods described in Barbieri et al. (1994) with a few modifications. Briefly, the left or right sagittal otolith was randomly selected and attached to a glass slide with Electron Microscopy Sciences' clear Crystalbond™ 509 adhesive. At least one transverse cross-section was cut through the core of each otolith using a Buehler Isomet low-speed saw equipped with two, three inch, fine- grit Norton diamond-wheel wafering blades, separated by a spacer of 0.3mm. Otolith sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but, more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 1).

All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 267 for ageing spot in 2007, ranging in length interval from 5 to 13 inches (Table 1). This sample size provided a range in CV for age composition approximately from the CV much smaller than 5% for age 1 and the largest CV of 16% for age 3 fish. In 2007, we randomly selected and aged 246 fish from 342 Spot collected by VMRC. We were short of 45 fish compared to the optimum ageing sample size, mainly from larger fish (Table 1), therefore, the precision for older fish would be influenced significantly.

The measurement of reader self-precision was good for both readers (Reader 1's CV = 3.4% and Reader 2's CV = 1.9%). Figure 2 illustrates the between readers' precision of age estimates. There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: χ^2 = 5.67, df = 4, P = 0.2255). The average between-reader coefficient of variation (CV) of 1.9% was good with an agreement of 96% between two readers.

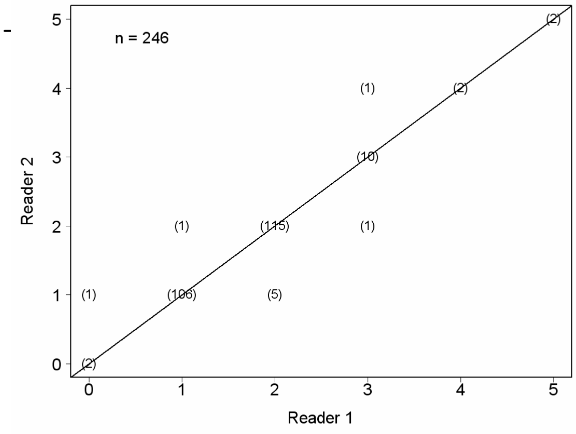


Figure 2. Between-reader comparison of otolith age estimates for spot in 2007.

Of the 246 fish aged with otoliths, 6 age classes were represented (Table 2). The average age for the sample was 1.6 years old, and the standard deviation and standard error were 0.7 and 0.04, respectively.

Year-class data (Figure 3) show that the fishery was comprised of 6 year-classes, with fish spawned in both 2005 and 2006 dominating the catch.

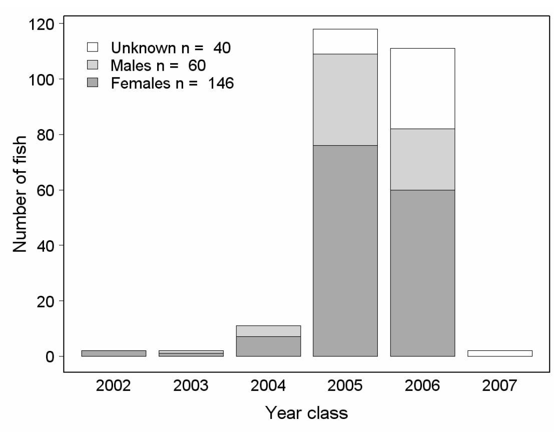


Figure 3. Year-class frequency distribution for spot collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

S-Plus. 1999. S-Plus 4.5 Guide to Statistics. Data Analysis Products Division. Math Soft, Inc. Seattle, Washington.

List of Tables

Table 1. Number of spot collected and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
5	5	5	3	2
6	5	21	6	0
7	23	66	26	0
8	49	85	54	0
9	80	84	82	0
10	49	68	62	0
11	34	9	9	25
12	17	2	2	15
13	5	2	2	3
Totals	267	342	246	45

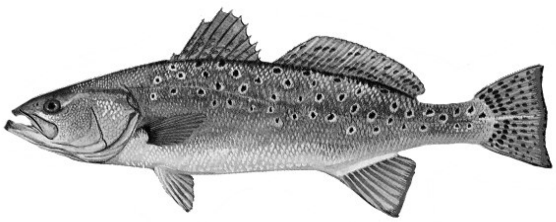
Table 2. The number of spot assigned to each total length-at-age category for 246 fish sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years)						
	0	1	2	3	4	5	Totals
5	2	1	0	0	0	0	3
6	0	6	0	0	0	0	6
7	0	21	5	0	0	0	26
8	0	21	31	2	0	0	54
9	0	30	50	2	0	0	82
10	0	31	26	4	1	0	62
11	0	1	6	2	0	0	9
12	0	0	0	1	1	0	2
13	0	0	0	0	0	2	2
Totals	2	111	118	11	2	2	246

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for spot sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5
5	0.667	0.333	0.000	0.000	0.000	0.000
6	0.000	1.000	0.000	0.000	0.000	0.000
7	0.000	0.808	0.192	0.000	0.000	0.000
8	0.000	0.389	0.574	0.037	0.000	0.000
9	0.000	0.366	0.610	0.024	0.000	0.000
10	0.000	0.500	0.419	0.065	0.016	0.000
11	0.000	0.111	0.667	0.222	0.000	0.000
12	0.000	0.000	0.000	0.500	0.500	0.000
13	0.000	0.000	0.000	0.000	0.000	1.000

Chapter 9
Spotted Seatrout



Cynoscion nebulosus

INTRODUCTION

We aged a total of 186 spotted seatrout, *Cynoscion nebulosus*, collected by the VMRC's Biological Sampling Program in 2007. The average age for the sample was 1.90 years old, and the standard deviation and standard error were 1.09 and 0.08, respectively. Eight age classes (0 to 6 and 9) were represented, comprising fish from the 1998, and 2001 through 2007 year-classes, with fish primarily from the 2005 year-classes.

METHODS

Sample size for ageing — We estimated sample size for ageing spotted seatrout in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing spotted seatrout in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of spotted seatrout collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of spotted seatrout used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which is only a 1% CV reduction is achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. They were sorted based on date of capture, their

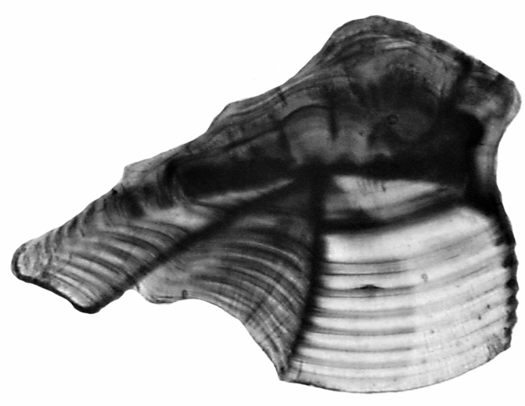


Figure 1. Sectioned otolith from an 8 year old male spotted seatrout.

envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory sample number. All otoliths were stored in their original VMRC coin envelopes.

Preparation — Otoliths were processed following the methods described in Barbieri et al. (1994) with a few modifications. Briefly, the left or right sagittal otolith was randomly selected and attached to a glass slide with Electron Microscopy Sciences' clear Crystalbond™ 509 adhesive. At least one transverse cross-section was cut through the core of each otolith using a Buehler Isomet low-speed saw equipped with two, three inch, fine- grit Norton diamond-wheel wafering blades, separated by a spacer of 0.3mm. Otolith sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but, more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 1). All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 156 for ageing spotted seatrout in 2007, ranging in length interval from 7 to 30 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 4% for age 1 and the largest CV of 24% for age 4 fish. In 2007, we randomly selected and aged 186 fish from 293 spotted seatrout collected by VMRC. We were short of 23 fish compared to the optimum ageing sample size, mainly from the large fish (Table 1), therefore, the precision for older fish would be influenced significantly.

The measurement of reader self-precision was very high with the CV of 0 for both readers. Figure 2 illustrates the between readers' precision of age estimates. There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 1$, df = 1, P = 0.3173). The average between-reader coefficient of variation (CV) of 0.2% was very good with an agreement of 99% between two readers.

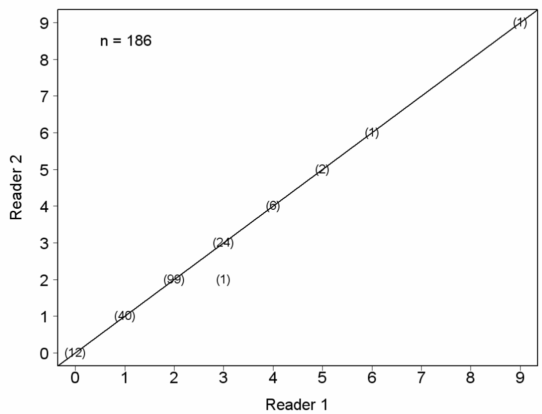


Figure 2. Between-reader comparison of otolith age estimates for spotted seatrout in 2007.

Of the 186 fish aged with otoliths, 8 age classes were represented (Table 2). The average age for the sample was 1.9 years old, and the standard deviation and standard error were 0.9 and 0.08, respectively.

Year-class data (Figure 3) show that the fishery was comprised of 8 year-classes, comprising fish from the 1998, 2001-2007 year-classes, with fish primarily from the 2005 year-classes.

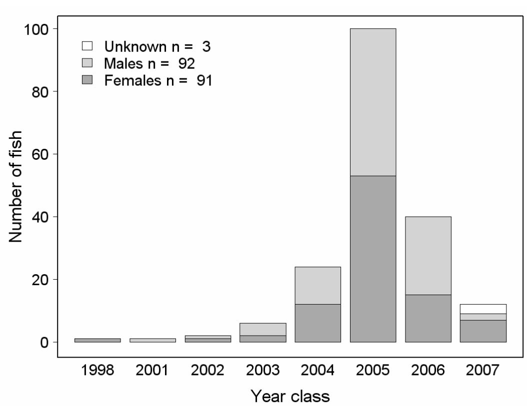


Figure 3. Year-class frequency distribution for spotted seatrout collected for ageing in 2007. Distribution is broken down by sex. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

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S-Plus. 1999. S-Plus 4.5 Guide to Statistics. Data Analysis Products Division. Math Soft, Inc. Seattle, Washington.

List of Tables

Table 1. Number of spotted seatrout collected and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
7	0	1	1	0
8	0	3	3	0
9	5	1	1	4
10	5	7	5	0
11	7	13	8	0
12	16	13	13	3
13	14	12	12	2
14	9	9	9	0
15	7	27	15	0
16	7	40	16	0
17	15	33	16	0
18	7	32	16	0
19	13	35	16	0
20	10	23	16	0
21	8	12	10	0
22	5	14	12	0
23	7	9	8	0
24	6	0	0	6
25	5	4	4	1
26	5	2	2	3
27	5	1	1	4
28	0	1	1	0
30	0	1	1	0
Totals	156	293	186	23

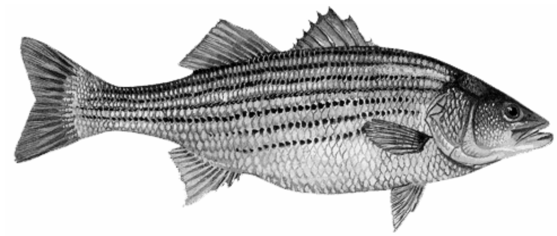
Table 2. The number of spotted seatrout assigned to each total length-at-age category for 186 spotted seatrout sampled for otolith age determination in Virginia during 2007.

Length 1-inch interval	Age (years)								
	0	1	2	3	4	5	6	9	Totals
7	1	0	0	0	0	0	0	0	1
8	3	0	0	0	0	0	0	0	3
9	0	0	1	0	0	0	0	0	1
10	0	3	2	0	0	0	0	0	5
11	4	3	1	0	0	0	0	0	8
12	2	11	0	0	0	0	0	0	13
13	2	10	0	0	0	0	0	0	12
14	0	6	3	0	0	0	0	0	9
15	0	2	13	0	0	0	0	0	15
16	0	0	16	0	0	0	0	0	16
17	0	3	13	0	0	0	0	0	16
18	0	1	14	1	0	0	0	0	16
19	0	1	12	3	0	0	0	0	16
20	0	0	13	2	1	0	0	0	16
21	0	0	7	3	0	0	0	0	10
22	0	0	3	7	2	0	0	0	12
23	0	0	2	5	0	1	0	0	8
25	0	0	0	1	2	0	1	0	4
26	0	0	0	1	1	0	0	0	2
27	0	0	0	1	0	0	0	0	1
28	0	0	0	0	0	1	0	0	1
30	0	0	0	0	0	0	0	1	1
Totals	12	40	100	24	6	2	1	1	186

Table 3. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for spotted seatrout sampled for age determination in Virginia during 2007.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	9
7	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.600	0.400	0.000	0.000	0.000	0.000	0.000
11	0.500	0.375	0.125	0.000	0.000	0.000	0.000	0.000
12	0.154	0.846	0.000	0.000	0.000	0.000	0.000	0.000
13	0.167	0.833	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.667	0.333	0.000	0.000	0.000	0.000	0.000
15	0.000	0.133	0.867	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.188	0.812	0.000	0.000	0.000	0.000	0.000
18	0.000	0.062	0.875	0.062	0.000	0.000	0.000	0.000
19	0.000	0.062	0.750	0.188	0.000	0.000	0.000	0.000
20	0.000	0.000	0.812	0.125	0.062	0.000	0.000	0.000
21	0.000	0.000	0.700	0.300	0.000	0.000	0.000	0.000
22	0.000	0.000	0.250	0.583	0.167	0.000	0.000	0.000
23	0.000	0.000	0.250	0.625	0.000	0.125	0.000	0.000
25	0.000	0.000	0.000	0.250	0.500	0.000	0.250	0.000
26	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000
27	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
30	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000

Chapter 10
Striped Bass



Morone saxatilis

INTRODUCTION

We aged a total of 800 striped bass, *Morone saxatilis*, using their scales collected by the VMRC's Biological Sampling Program in 2007. Of 800 aged fish, 613 and 187 fish were collected in Chesapeake Bay (bay fish) and Atlantic waters (ocean fish) of Virginia, respectively. The average age for the bay fish was 8.4 years with a standard deviation of 2.94 and a standard error of 0.12. Sixteen age classes (3 to 18) were represented in the bay fish, comprising fish from the 1998 through 2004 year classes. The year classes of 1995 through 2003 were dominant in the bay fish sample in 2007. The average age for the ocean fish was 9.6 years with a standard deviation of 2.2 and a standard error of 0.16. Eleven age classes (5 to 14 and 16) were represented in the ocean fish, comprising fish from the 1991, 1993 to 2002 year classes. The year classes of 1995 through 2001 were dominant in the ocean fish sample in 2007. We also aged a total of 532 fish using their otoliths in addition to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were to one another (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing striped bass collected in both Chesapeake Bay and Atlantic waters of Virginia in 2007, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing striped bass in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of striped bass collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of striped bass used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths and scales were received by the Age & Growth Laboratory in labeled coin envelopes.

Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory sample number. All otoliths and scales were stored in their original VMRC coin envelopes.

Preparation —

Scales – Striped bass scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and which were of uniform size. We selected a range of four to six preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear 020 acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure:	15000 psi
Temperature:	77°C (170°F)
Time:	5 to 10 min

Striped bass scales that were the size of a quarter (coin) or larger, were pressed individually for up to twenty minutes. After pressing, the impressions were viewed with a Bell and Howell microfiche reader and checked again for regeneration and incomplete margins. Impressions that were too light, or when all scales were regenerated a new impression was made using different scales from the same fish.

Otoliths — We used a thin-section and bake technique to process striped bass otoliths for age determination. Otolith preparation began by randomly selecting either the right or left otolith. The otolith was mounted with Crystal Bond onto a standard microscope slide with its distal surface orientated upwards. Once mounted, a small mark was placed on the otolith surface directly above the otolith focus. The slide, with attached otolith, was then secured to an Isomet saw equipped with two diamond wafering blades separated by a 0.4 mm spacer, which was slightly smaller in diameter than the diamond blades. The otolith was positioned so that the wafering blades straddled each side of the otolith focus ink mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the otolith section was placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was otolith size dependent and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — By convention, a birth date of January 1 is assigned to all Northern Hemisphere fish species. We use a system of age determination that assigns age class according to the date of sacrifice with respect to this international accepted birthdate and the timing of annulus formation, which occurs between the months of May and June for striped bass. Once the reader decides how many annuli are visible on the ageing structure, the year class is assigned. The year class designation, or age, is written first followed by the actual number of annuli visible listed within brackets (e.g. 3(3)). The presence of a "+" after the number in the brackets indicates new growth, or "plus growth" visible on the structure's margin. Using this method, a fish sacrificed in January before annulus formation with three visible annuli would be assigned the same age, 4(3+), as a fish with four visible annuli sacrificed in July after annulus formation, 4(4).

Two different readers aged all samples in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the age readers were unable to agree on a final age, the fish was excluded from further analysis.

Figure 1. Scale impression of a 5-year-old male striped bass.

Scales - We determined fish age by viewing acetate impressions of scales (Figure 1) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses.

Annuli on striped bass scales are identified based on two scale microstructure features, "crossing over" and circuli disruption. Primarily, "crossing over" in the lateral margins near the posterior\anterior interface of the scale is used to determine the origin of the annulus. Here compressed circuli (annulus) "cross over" the previously deposited circuli of the previous year's growth. Typically annuli of the first three years can be observed transversing this interface as dark bands. These bands remain consistent throughout the posterior field and rejoin the posterior\anterior interface on the opposite side of the focus. Annuli can also be observed in the anterior lateral field of the scale. Here the annuli typically reveal a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are typically associated with the disruption of circuli.

Annuli can also be observed bisecting the perpendicular plain of the radial striations in the anterior field of the scale. Radii emanate out from the focus of the scale towards the outer corner margins of the anterior field. These radial striations consist mainly of segmented concave circuli. The point of intersection between radii and annuli results in a "straightening out" of the concave circuli. This straightening of the circuli should be consistent throughout the entire anterior field of the scale. This event is further amplified by the presence of concave circuli neighboring both directly above and below the annulus.

The first year's annulus can be difficult to locate on some scales. It is typically best identified in the lateral field of the anterior portion of the scale. The distance from the focus to the first year's annulus is typically larger with respect to the following few annuli. For the annuli two through six, summer growth generally decreases proportionally. For ages greater than six, a crowding effect of the annuli near the outer margins of the scale is observed. This crowding effect creates difficulties in edge interpretation. At this point it is best to focus on the straightening of the circuli at the anterior margins of the scale.

When ageing young striped bass, zero through age two, extreme caution must be taken as not to over age the structure. In young fish there is no point of reference to aid in the determination of the first year; this invariably results in over examination of the scale and such events as hatching or saltwater incursion marks (checks) may be interpreted as the first year.

Otoliths – Sectioned otoliths were aged by two different readers using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 2).

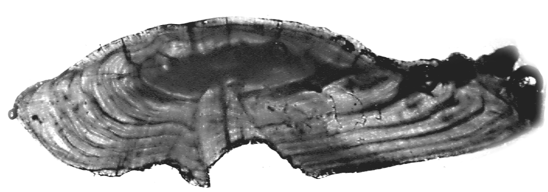


Figure 2. Otolith thin-section of a 5-year-old male striped bass.

By convention an annulus is identified as the narrow opaque zone, or winter growth. Typically the first year's annulus can be determined by first locating the focus of the otolith. The focus is generally located, depending on preparation, in the center of the otolith, and is visually well defined as a dark oblong region. The first year's annulus can be located directly below the focus, along the outer ridge of the sulcal groove on the ventral and dorsal sides of the otolith. This insertion point along the sulcal ridge resembles a check mark (not to be confused with a false annulus). Here the annulus can be followed outwards along the ventral and dorsal surfaces where it encircles the focus. Subsequent annuli also emanate from the sulcal ridge, however, they do not encircle the focus, but rather travel outwards to the distal surface of the otolith. To be considered a true annulus, each annulus must be rooted in the sulcus and travel without interruption to the distal surface of the otolith. The annuli in striped bass have a tendency to split as they advance towards the distal surface. As a result, it is critical that reading path proceed in a direction down the sulcal ridge and outwards to the distal surface.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 653 for ageing the bay striped bass in 2007, ranging in length interval from 12 to 54 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 10% for age 7 and the largest CV of 23% for age 3 and 13 of the bay fish. We randomly selected and aged

613 fish from 718 striped bass collected by VMRC in 2007. We were short of 92 fish mainly in the very small and large length intervals (Table 1), as a result, the precision for the estimates of major ages would not be influenced significantly.

We estimated a sample size of 572 for ageing the ocean striped bass in 2007, ranging in length interval from 20 to 54 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 9 and the largest CV of 18% for age 13 of the ocean fish. We aged 187 of 188 striped bass collected by VMRC in 2007. We were not able to age one fish due to the scale damage. We were short of 400 fish in total from among almost all of the length intervals (Table 2), as a result, the precision for the estimates of all age groups would be influenced significantly. Apparently, we had a good year for the bay but not for the ocean striped bass in 2007.

Scales — Measurements of reader self-precision was fair for Reader 1 (CV = 4.3%) and low for Reader 2 (CV = 8%). There was evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 54.94$, df = 37, P =0.0290). In Figure 3 we present a graph of the results for between-reader scale ageing precision. The average between-reader coefficient of variation (CV) of 4.5% was fair. The between-reader agreement for scale for one year or less was 90% of all aged fish higher than 85% in 2006.

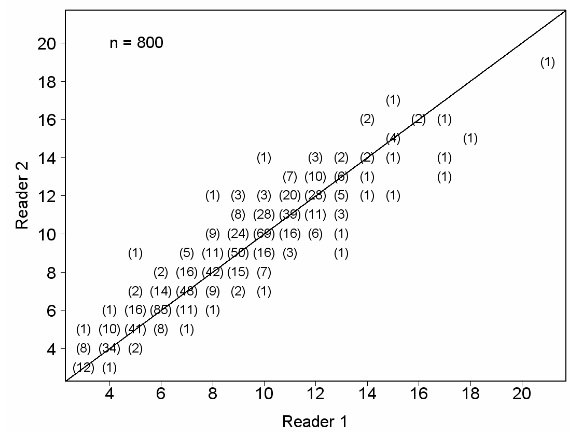


Figure 3. Between-reader comparison of scale age estimates for striped bass in 2007.

Of the 613 bay striped bass aged with scales, 16 age classes (3 to 18) were represented (Table 3). The average age for the sample was 8.4 years. The standard deviation and standard error were 2.94 and 0.12, respectively. Year-class data (Figure 4) indicates that recruitment into the fishery in Chesapeake Bay begins at age 3, which corresponds to the 2004 year-class for striped bass caught in 2007. Striped bass appear to fully recruit to the fishery at age 11 (1996 year-class).

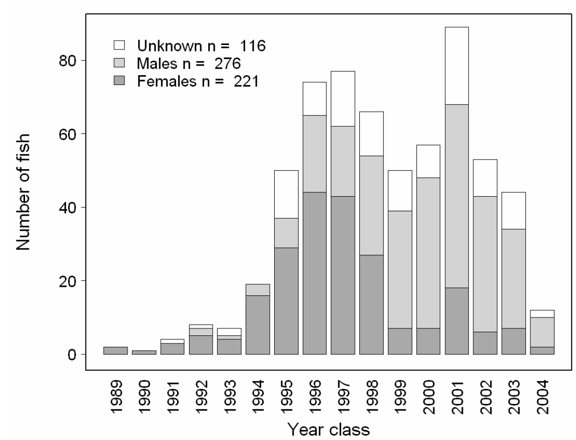


Figure 4. Year-class frequency distribution for striped bass collected in Chesapeake Bay of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using scale ages. "

Of the 187 ocean striped bass aged with scales, 11 age classes (5 to 14 and 16) were represented (Table 4). The average age for the sample was 9.6 years. The standard deviation and standard error were 2.2 and 0.16, respectively. Year-class data (Figure 5) indicates that recruitment into the fishery in Atlantic waters of Virginia begins at age 5, which corresponds to the 2002 year-class for striped bass caught in 2007. Striped bass appear to fully recruit to the fishery at age 10 (1997 year-class).

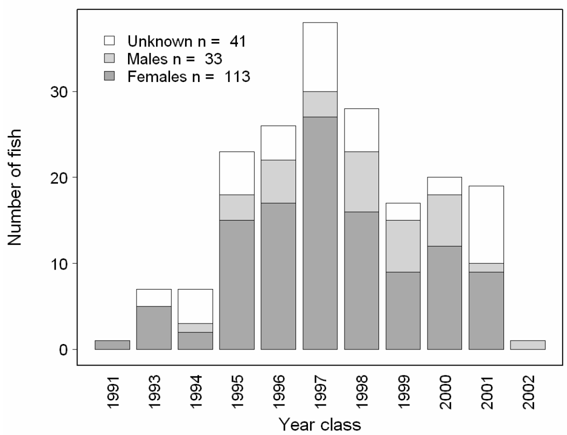


Figure 5. Year-class frequency distribution for striped bass collected in Atlantic waters of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using scale ages. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Otoliths — Measurements of reader self-precision were good, with both readers able to reproduce the ages of previously read otoliths (Reader 1's CV = 2.2% and Reader 2's CV = 1.2%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: χ^2 = 22.72, df = 24, P = 0.5362). In Figure 6 we present a graph of the results for between-reader otolith ageing precision. The average between-reader coefficient of variation (CV) of 1.8% was not significant and similar to the CV of 2% in 2006. The between-reader agreement for otoliths for one year or less was 98% of all aged fish.

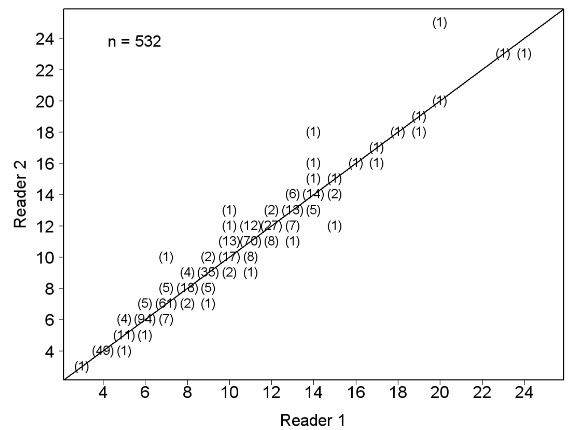


Figure 6. Between-reader comparison of otolith age estimates for striped bass in 2007.

Of 532 fish aged with otoliths, 21 age classes (3 to 20, and 22 to 24) were represented for striped bass aged with otoliths. The average age for the sample was 8.8 years. The standard deviation and standard error were 3.3 and 0.14, respectively.

Comparison of Scale and Otolith Ages — we aged 532 striped bass using both their scales and otoliths. There was evidence of systematic disagreement between otolith and scale ages (test of symmetry: χ^2 = 147.76, df = 50, P < 0.0001) with an average CV of 9.9%. Scales were assigned a lower age than otoliths for 47% of the fish and 22% of the time were scales assigned a higher age than otoliths (Figure 7). There was also evidence of bias between otolith and scale ages using an age bias plot (Figure 8), again with scale generally assigned higher ages for younger fish and lower ages for older fish than otoliths age estimates.

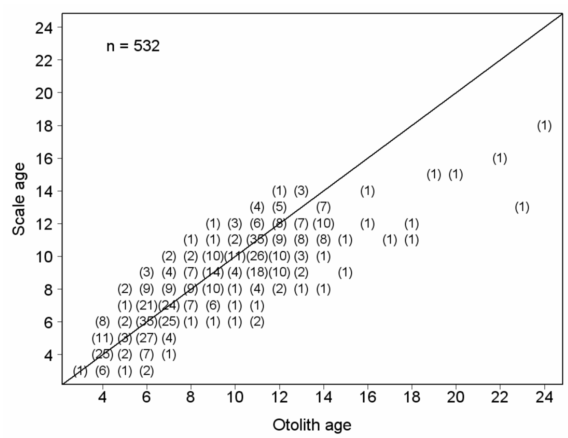


Figure 7. Comparison of scale and otolith age estimates for striped bass in 2007.

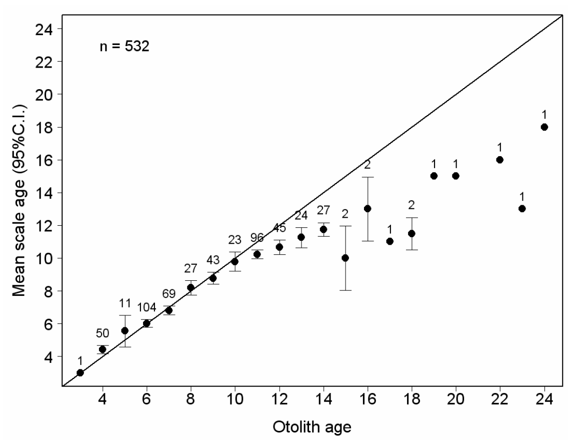


Figure 8. Age-bias plot for striped bass scale and otolith age estimates in 2007.

Age-Length-Key — In Table 5 and 6, we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

RECOMMENDATIONS

•We recommend that VMRC and ASMFC use otoliths for ageing striped bass. Although preparation time is greater for otoliths compared to scales, nonetheless as the mean age of striped bass increases in the recovering fishery, otoliths should provide more reliable estimates of age. We will continue to compare the age estimates between otoliths and scales.

REFERENCES

Campana, S.E., M.C. Annand, and J.I. McMillan. 1995. Graphical and statistical methods for determining the consistency of age determinations. Trans. Am. Fish. Soc. 124:131-138.

Hoenig, J.M., M.J. Morgan, and C.A. Brown. 1995. Analysing differences between two age determination methods by tests of symmetry. Can. J. Fish. Aquat. Sci. 52:364-368.

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Table 1. Number of striped bass collected in the Chesapeake Bay of Virginia in 2007 and scale-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
12	5	0	0	5
13	5	0	0	5
14	5	0	0	5
15	5	0	0	5
16	5	0	0	5
17	5	2	2	3
18	10	10	10	0
19	20	24	20	0
20	22	36	23	0
21	26	56	28	0
22	32	47	36	0
23	36	52	38	0
24	34	37	37	0
25	33	38	35	0
26	26	31	28	0
27	25	36	28	0
28	21	31	22	0
29	17	20	19	0
30	16	16	16	0
31	17	25	19	0
32	22	25	25	0
33	23	24	24	0
34	31	23	23	8
35	31	33	33	0
36	41	46	44	0
37	33	39	37	0
38	16	14	14	2
39	11	13	13	0
40	10	6	6	4
41	5	12	11	0
42	5	12	12	0
43	5	4	4	1
44	5	1	1	4
45	5	2	2	3
46	5	1	1	4
47	5	2	2	3
48	5	0	0	5
49	5	0	0	5
50	5	0	0	5
51	5	0	0	5
52	5	0	0	5
53	5	0	0	5
54	5	0	0	5
Totals	653	718	613	92

Table 2. Number of striped bass collected in Atlantic waters of Virginia in 2007 and scale-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
20	5	0	0	5
21	5	0	0	5
22	5	0	0	5
23	5	0	0	5
24	5	0	0	5
25	5	0	0	5
26	5	0	0	5
27	5	3	3	2
28	12	8	8	4
29	11	21	21	0
30	20	14	14	6
31	23	15	15	8
32	36	18	17	19
33	57	13	13	44
34	66	12	12	54
35	68	11	11	57
36	63	16	16	47
37	62	18	18	44
38	23	11	11	12
39	12	5	5	7
40	10	3	3	7
41	5	10	10	0
42	4	3	3	1
43	5	2	2	3
44	5	1	1	4
45	5	3	3	2
46	5	1	1	4
47	5	0	0	5
48	5	0	0	5
49	5	0	0	5
50	5	0	0	5
51	5	0	0	5
52	5	0	0	5
53	5	0	0	5
54	5	0	0	5
Totals	572	188	187	400

Table 3. The number of striped bass assigned to each total length-at-age category for 613 fish sampled for scale age determination in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years) 3	4	5	6	7	8	9	10	11
17	1	1	0	0	0	0	0	0	0
18	1	7	2	0	0	0	0	0	0
19	2	10	5	3	0	0	0	0	0
20	2	7	6	6	2	0	0	0	0
21	2	5	5	10	4	2	0	0	0
22	3	8	8	10	4	1	1	0	1
23	1	1	7	14	7	5	2	1	0
24	0	3	6	9	10	6	2	1	0
25	0	1	3	11	4	5	7	3	1
26	0	0	3	10	1	9	3	2	0
27	0	0	6	3	8	3	2	2	2
28	0	1	1	7	4	4	2	2	1
29	0	0	1	2	2	3	2	3	3
30	0	0	0	2	3	0	3	4	1
31	0	0	0	1	2	2	2	3	5
32	0	0	0	0	2	4	5	8	3
33	0	0	0	0	1	2	3	7	5
34	0	0	0	1	3	0	11	2	4
35	0	0	0	0	0	3	5	7	10
36	0	0	0	0	0	0	6	16	11
37	0	0	0	0	0	1	6	12	13
38	0	0	0	0	0	0	2	3	4
39	0	0	0	0	0	0	1	1	6
40	0	0	0	0	0	0	0	0	2
41	0	0	0	0	0	0	0	0	1
42	0	0	0	0	0	0	1	0	1
43	0	0	0	0	0	0	0	0	0
44	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	0	0
Totals	12	44	53	89	57	50	66	77	74

Table 3. Continued

Length 1-inch interval	Age (years) 12	13	14	15	16	17	18	Totals
17	0	0	0	0	0	0	0	2
18	0	0	0	0	0	0	0	10
19	0	0	0	0	0	0	0	20
20	0	0	0	0	0	0	0	23
21	0	0	0	0	0	0	0	28
22	0	0	0	0	0	0	0	36
23	0	0	0	0	0	0	0	38
24	0	0	0	0	0	0	0	37
25	0	0	0	0	0	0	0	35
26	0	0	0	0	0	0	0	28
27	2	0	0	0	0	0	0	28
28	0	0	0	0	0	0	0	22
29	3	0	0	0	0	0	0	19
30	2	1	0	0	0	0	0	16
31	4	0	0	0	0	0	0	19
32	3	0	0	0	0	0	0	25
33	4	2	0	0	0	0	0	24
34	1	1	0	0	0	0	0	23
35	5	2	1	0	0	0	0	33
36	8	2	0	0	1	0	0	44
37	4	0	0	1	0	0	0	37
38	3	1	1	0	0	0	0	14
39	4	1	0	0	0	0	0	13
40	2	2	0	0	0	0	0	6
41	2	3	3	2	0	0	0	11
42	3	2	1	4	0	0	0	12
43	0	0	1	1	1	1	0	4
44	0	0	0	0	1	0	0	1
45	0	2	0	0	0	0	0	2
46	0	0	0	0	0	0	1	1
47	0	0	0	0	1	0	1	2
Totals	50	19	7	8	4	1	2	613

Table 4. The number of striped bass assigned to each total length-at-age category for 187 fish sampled for scale age determination in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years)										
	5	6	7	8	9	10	11	12	13	14	16	Totals
27	0	1	0	1	1	0	0	0	0	0	0	3
28	1	0	5	1	1	0	0	0	0	0	0	8
29	0	11	5	2	3	0	0	0	0	0	0	21
30	0	5	2	1	4	1	1	0	0	0	0	14
31	0	2	4	3	1	3	1	0	1	0	0	15
32	0	0	3	4	3	2	4	1	0	0	0	17
33	0	0	0	2	3	3	2	3	0	0	0	13
34	0	0	0	2	1	4	2	3	0	0	0	12
35	0	0	0	1	5	1	3	1	0	0	0	11
36	0	0	0	0	4	5	2	1	2	2	0	16
37	0	0	1	0	0	7	2	4	1	3	0	18
38	0	0	0	0	1	5	3	2	0	0	0	11
39	0	0	0	0	0	2	0	1	2	0	0	5
40	0	0	0	0	0	0	2	1	0	0	0	3
41	0	0	0	0	1	3	2	3	1	0	0	10
42	0	0	0	0	0	2	0	0	0	1	0	3
43	0	0	0	0	0	0	0	1	0	1	0	2
44	0	0	0	0	0	0	0	0	0	0	1	1
45	0	0	0	0	0	0	1	2	0	0	0	3
46	0	0	0	0	0	0	1	0	0	0	0	1
Totals	1	19	20	17	28	38	26	23	7	7	1	187

Table 5. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for striped bass sampled in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years) 3	4	5	6	7	8	9	10
17	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000
18	0.100	0.700	0.200	0.000	0.000	0.000	0.000	0.000
19	0.100	0.500	0.250	0.150	0.000	0.000	0.000	0.000
20	0.087	0.304	0.261	0.261	0.087	0.000	0.000	0.000
21	0.071	0.179	0.179	0.357	0.143	0.071	0.000	0.000
22	0.083	0.222	0.222	0.278	0.111	0.028	0.028	0.000
23	0.026	0.026	0.184	0.368	0.184	0.132	0.053	0.026
24	0.000	0.081	0.162	0.243	0.270	0.162	0.054	0.027
25	0.000	0.029	0.086	0.314	0.114	0.143	0.200	0.086
26	0.000	0.000	0.107	0.357	0.036	0.321	0.107	0.071
27	0.000	0.000	0.214	0.107	0.286	0.107	0.071	0.071
28	0.000	0.045	0.045	0.318	0.182	0.182	0.091	0.091
29	0.000	0.000	0.053	0.105	0.105	0.158	0.105	0.158
30	0.000	0.000	0.000	0.125	0.188	0.000	0.188	0.250
31	0.000	0.000	0.000	0.053	0.105	0.105	0.105	0.158
32	0.000	0.000	0.000	0.000	0.080	0.160	0.200	0.320
33	0.000	0.000	0.000	0.000	0.042	0.083	0.125	0.292
34	0.000	0.000	0.000	0.043	0.130	0.000	0.478	0.087
35	0.000	0.000	0.000	0.000	0.000	0.091	0.152	0.212
36	0.000	0.000	0.000	0.000	0.000	0.000	0.136	0.364
37	0.000	0.000	0.000	0.000	0.000	0.027	0.162	0.324
38	0.000	0.000	0.000	0.000	0.000	0.000	0.143	0.214
39	0.000	0.000	0.000	0.000	0.000	0.000	0.077	0.077
40	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
41	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
42	0.000	0.000	0.000	0.000	0.000	0.000	0.083	0.000
43	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
45	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
46	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
47	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

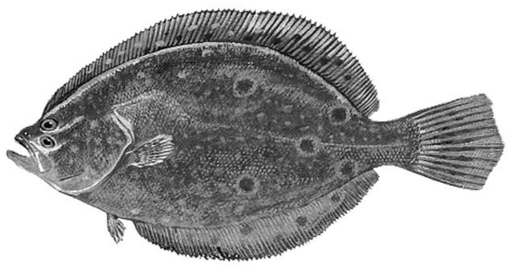
Table 5. Continued

Length 1-inch interval	Age (years) 11	12	13	14	15	16	17	18
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.028	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
25	0.029	0.000	0.000	0.000	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
27	0.071	0.071	0.000	0.000	0.000	0.000	0.000	0.000
28	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000
29	0.158	0.158	0.000	0.000	0.000	0.000	0.000	0.000
30	0.062	0.125	0.062	0.000	0.000	0.000	0.000	0.000
31	0.263	0.211	0.000	0.000	0.000	0.000	0.000	0.000
32	0.120	0.120	0.000	0.000	0.000	0.000	0.000	0.000
33	0.208	0.167	0.083	0.000	0.000	0.000	0.000	0.000
34	0.174	0.043	0.043	0.000	0.000	0.000	0.000	0.000
35	0.303	0.152	0.061	0.030	0.000	0.000	0.000	0.000
36	0.250	0.182	0.045	0.000	0.000	0.023	0.000	0.000
37	0.351	0.108	0.000	0.000	0.027	0.000	0.000	0.000
38	0.286	0.214	0.071	0.071	0.000	0.000	0.000	0.000
39	0.462	0.308	0.077	0.000	0.000	0.000	0.000	0.000
40	0.333	0.333	0.333	0.000	0.000	0.000	0.000	0.000
41	0.091	0.182	0.273	0.273	0.182	0.000	0.000	0.000
42	0.083	0.250	0.167	0.083	0.333	0.000	0.000	0.000
43	0.000	0.000	0.000	0.250	0.250	0.250	0.250	0.000
44	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000
45	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
46	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
47	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.500

Table 6. Age-Length key, as proportion-at-age in each 1-inch length interval, based on scale ages for striped bass sampled in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years)										
	5	6	7	8	9	10	11	12	13	14	16
27	0.000	0.333	0.000	0.333	0.333	0.000	0.000	0.000	0.000	0.000	0.000
28	0.125	0.000	0.625	0.125	0.125	0.000	0.000	0.000	0.000	0.000	0.000
29	0.000	0.524	0.238	0.095	0.143	0.000	0.000	0.000	0.000	0.000	0.000
30	0.000	0.357	0.143	0.071	0.286	0.071	0.071	0.000	0.000	0.000	0.000
31	0.000	0.133	0.267	0.200	0.067	0.200	0.067	0.000	0.067	0.000	0.000
32	0.000	0.000	0.176	0.235	0.176	0.118	0.235	0.059	0.000	0.000	0.000
33	0.000	0.000	0.000	0.154	0.231	0.231	0.154	0.231	0.000	0.000	0.000
34	0.000	0.000	0.000	0.167	0.083	0.333	0.167	0.250	0.000	0.000	0.000
35	0.000	0.000	0.000	0.091	0.455	0.091	0.273	0.091	0.000	0.000	0.000
36	0.000	0.000	0.000	0.000	0.250	0.312	0.125	0.062	0.125	0.125	0.000
37	0.000	0.000	0.056	0.000	0.000	0.389	0.111	0.222	0.056	0.167	0.000
38	0.000	0.000	0.000	0.000	0.091	0.455	0.273	0.182	0.000	0.000	0.000
39	0.000	0.000	0.000	0.000	0.000	0.400	0.000	0.200	0.400	0.000	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	0.667	0.333	0.000	0.000	0.000
41	0.000	0.000	0.000	0.000	0.100	0.300	0.200	0.300	0.100	0.000	0.000
42	0.000	0.000	0.000	0.000	0.000	0.667	0.000	0.000	0.000	0.333	0.000
43	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.500	0.000
44	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
45	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.667	0.000	0.000	0.000
46	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000

Chapter 11
Summer Flounder



Paralichthys dentatus

INTRODUCTION

We aged a total of 540 summer flounder, *Paralichthys dentatus*, using their scales collected by the VMRC's Biological Sampling Program in 2006. Of 540 fish aged, 101 and 439 fish were collected in Chesapeake Bay (bay fish) and Atlantic waters (ocean fish) of Virginia, respectively. The average age for the bay fish was 4 years with a standard deviation of 1.35 and a standard error of 0.13. Eight age classes (1 to 8) were represented in the bay fish, comprising fish from the 1999-2006 year classes. The average age for the ocean fish was 4.3 years with a standard deviation of 1.71 and a standard error of 0.08. Ten age classes (2 – 11) were represented in the ocean fish, comprising fish from the 1996 to 2005 year classes. The 2002-2004 year class was dominant in both bay and ocean fish samples. We also aged a total of 423 fish using their otoliths additional to ageing their scales. The otolith ages were compared to the scale ages to examine how close both ages were (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing summer flounder collected in both Chesapeake Bay and Atlantic waters of Virginia in 2007, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing summer flounder in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of summer flounder collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of summer flounder used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths and scales were received by the Age & Growth Laboratory in labeled coin envelopes.

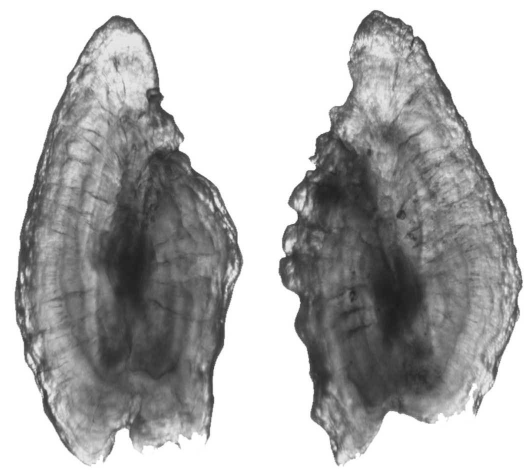
Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory sample number. All otoliths and scales were stored in their original VMRC coin envelopes.

Preparation —

<u>Scales</u> – Summer flounder scales were prepared for age and growth analysis by making acetate impressions of the scale microstructure. Due to extreme variation in the size and shape of scales from individual fish, we selected only those scales that had even margins and uniform size. We selected a range of five to ten preferred scales (based on overall scale size) from each fish, making sure that only non-regenerated scales were used. Scale impressions were made on extruded clear 020 acetate sheets (25 mm x 75 mm) with a Carver Laboratory Heated Press (model "C"). The scales were pressed with the following settings:

Pressure:	12000 to 15000 psi
Temperature:	Room temperature
Time:	7 minutes

<u>Otoliths</u> – The left otoliths of summer flounder are symmetrical in relation to the otolith nucleus, while right otoliths are asymmetrical (Figure 1). The right sagittal otolith was mounted with Aremco's clear Crystal Bond™ 509 adhesive onto a standard microscope slide with its distal surface orientated upwards. Once mounted, a small mark was placed on the otolith surface directly above the otolith focus. The slide, with attached otolith, was then secured to a Buehler Isomet saw equipped with two Norton diamond wafering blades separated by a 0.5 mm stainless steel spacer, which was slightly smaller in diameter than the diamond blades. The otolith was positioned so that the wafering blades straddled each side of the otolith focus ink mark. It was crucial that this cut be perpendicular to the long axis of the otolith. Failure to do so resulted in "broadening" and distortion of winter growth zones. A proper cut resulted in annuli that were clearly defined and delineated. Once cut, the otolith section was placed into a ceramic "Coors" spot plate well and baked in a Thermolyne 1400 furnace at 400°C. Baking time was otolith size dependent and gauged by color, with a light caramel color desired. Once a suitable color was reached the baked thin-section was placed on a labeled glass slide and covered with a thin layer of Flo-texx mounting medium, which provided enhanced contrast and greater readability by increasing light transmission through the sections.



(a) **(b)**

Figure 1. Whole otoliths from a 485 mm (total length) female summer flounder. (a) left otolith (b) right otolith.

Readings — By convention, a birth date of January 1 is assigned to all Northern

Hemisphere fish species. The Age and Growth Lab uses a system of age determination that assigns age class according to the date of sacrifice with respect to this international accepted birthdate and the timing of annulus formation, which occurs in Virginia's waters between the months of February and April. Using this method, a fish sacrificed in January before annulus formation with three visible annuli will be assigned the same age as a fish with four visible annuli sacrificed in July after annulus formation. Once the reader has decided how many annuli are visible on the ageing structure, the year class is assigned. The year class designation, or age, is written first followed by the actual number of annuli visible listed within brackets (e.g. 3(3)). The presence of a "+" after the number in the brackets indicates new growth, or "plus growth" visible on the structure's margin.

Two different readers aged all samples in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Scales - We determined fish age by viewing the acetate impressions of scales (Figure 2) with a standard Bell and Howell R-735 microfiche reader equipped with 20 and 29 mm lenses.

Annuli on summer flounder scales are primarily identified by the presence of crossing over of circuli. Crossing over is most evident on the lateral margins near the posterior/anterior interface of the scale. Here compressed circuli (annulus) "cross over" the deposited circuli of the previous year's growth. Typically the annulus will protrude partially into the ctenii of the posterior field, but not always.

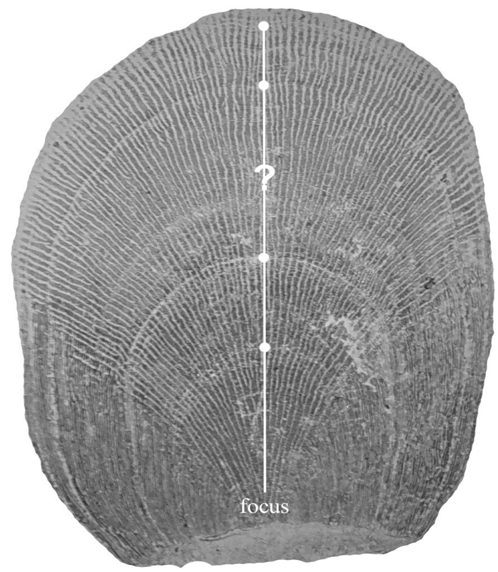


Figure 2. Scale impression of a 590 mm female summer flounder collected in November and aged as 4-years-old with scales. The question mark is located at a possible "3rd" annulus.

Following the annulus up into the anterior field of the scale reveals a pattern of discontinuous and suddenly breaking segmented circuli. This event can also be distinguished by the presence of concentric white lines, which are associated with the disruption of circuli. This pattern should be continuous throughout the entire anterior field of the scale. Locating the first annulus can be difficult due to latitudinal differences in growth rates and changes in the size of the first annulus due to a protracted spawning season. We consider the first annulus to be the first continuous crossing over event formed on the scale.

Otoliths – Sectioned otoliths were aged by two different readers using a Leica MZ-12 dissecting microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 3).

Summer flounder otoliths are composed of visually distinct summer and winter growth zones. By convention, an annulus is identified as the narrow opaque zone, or winter growth band. With sectioned otoliths, to be considered a true annulus, these growth bands must be rooted in the sulcus and able to be followed, without interruption to the distal surface of the otolith. The annuli in summer flounder have a tendency to split as they advance towards the distal surface. As a result, it is critical that the reading path proceeds in a direction from the sulcus to the proximal surface. The first annulus is located directly below the focus and near the upper portion of the sulcal groove. The distance from the focus to the first year is moderate, with translucent zone deposition gradually becoming smaller as consecutive annuli are deposited towards the outer edge.

Figure 3. Otolith section from a 590 mm, 6-year-old female summer flounder collected in November. Same fish as Figure 2.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 399 for ageing the bay summer flounder in 2007, ranging in length interval from 9 to 28 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 7% for age 2 and the largest CV of 24% for age 6 of the bay fish. We aged 101 summer flounder collected by VMRC in 2007, however, we still needed about 300 fish in total from among many length intervals (Table 1). As a result, the precision for the estimates of major age groups would be influenced significantly.

We estimated a sample size of 425 for ageing the ocean summer flounder in 2007, ranging in length interval from 9 to 29 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 8% for age 3 and the largest CV of 20% for age 8 of the ocean fish. We randomly selected and aged 439 fish from 1188 summer flounder collected by VMRC in 2007. We were short of 27 fish mainly from the very large and small length intervals (Table 2), therefore, the precision for the estimates of major age groups would not be influenced significantly. Apparently, we had a good year for the ocean but not for the bay summer flounder in 2007.

Scales — Measurements of reader self-precision was fair for Reader 1 (CV = 5.4% and good for Reader 2 (CV = 2%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 29.3$, df = 19, $P = 0.0614$), improved compared to 2006 ($P = 0.0003$). In Figure 4 we present a graph of the results for between-reader scale ageing precision. The average between-reader coefficient of variation (CV) of 4.3% was not significant. The between-reader agreement for scale for one year or less was 96% of all aged fish similar to 94% in 2006.

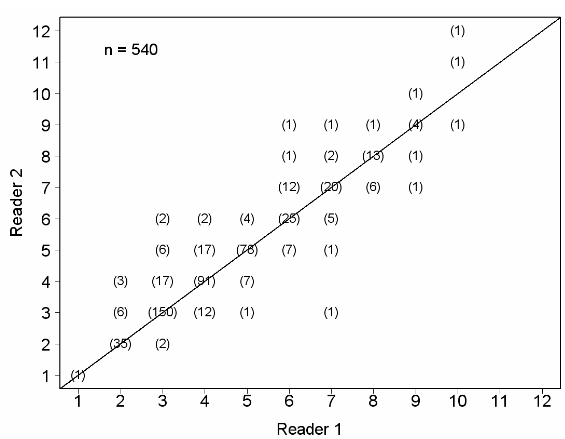


Figure 4.Between-reader comparison of scale age estimates for summer flounder in 2007.

Of the 101 bay fish aged with scales, 8 age-classes (1 and 8) were represented (Table 3). The average scale age was 4 years, and the standard deviation and standard error were 1.36 and 0.13, respectively. Year-class data (Figure 5) indicate that recruitment into the fishery in Chesapeake Bay began at age 1, which corresponds to the 2006 year-class for summer flounder caught in 2007. The 2002-2004 year class was dominant in the sample.

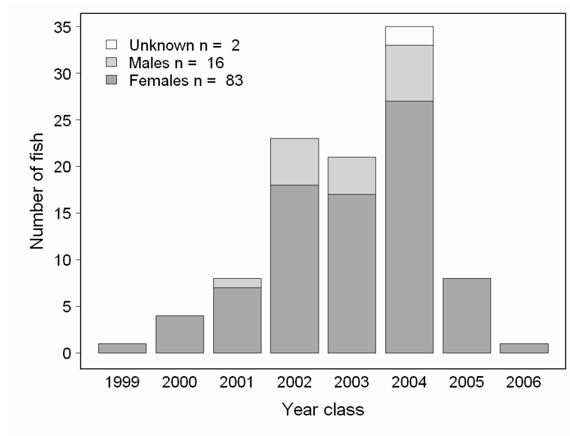


Figure 5. Year-class frequency distribution for summer flounder collected in Chesapeake Bay of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using scale ages. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Of the 439 ocean fish aged with scales, 10 age-classes (2 and 11) were represented (Table 4). The average scale age was 4.3 years, and the standard deviation and standard error were 1.71 and 0.08 respectively. Year-class data (Figure 6) indicate that recruitment into the fishery in Atlantic waters of Virginia began at age 2, which corresponds to the 2005 year-class for summer flounder caught in 2007. The 2002-2004 year class was dominant in the sample.

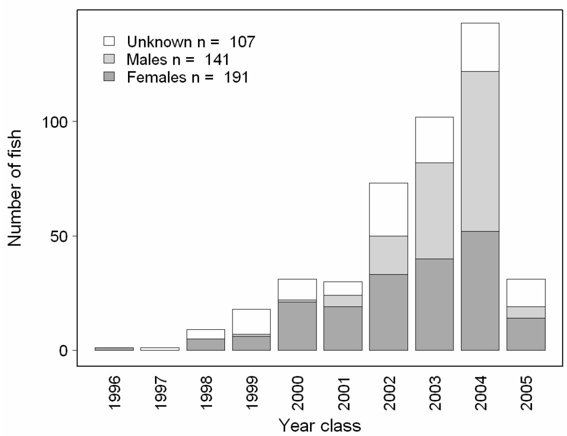


Figure 6. Year-class frequency distribution for summer flounder collected in Atlantic waters of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using scale ages. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

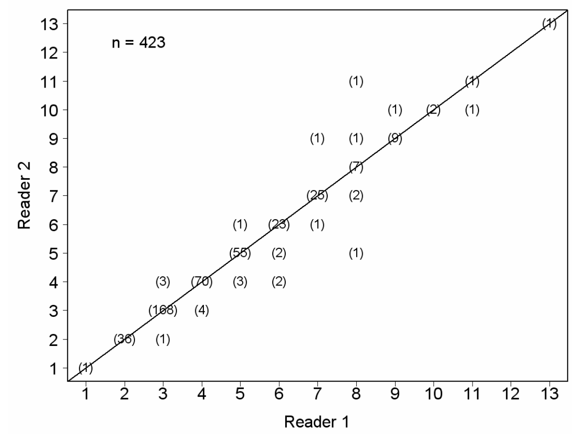


Figure 7. Between-reader comparison of otolith age estimates for summer flounder in 2007.

Otoliths — Measurements of reader self-precision were good for both readers (Reader 1's CV = 2.3% and Reader 2's CV = 1.1%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: χ^2 = 15.48, df = 13, P = 0.2786). In Figure 7 we present a graph of the results for between-reader otolith ageing precision. The average between-reader coefficient of variation (CV) of 1% was not significant with an agreement of 94% between two readers.

Of the 423 fish aged with otoliths, 12 age-classes (1 to 11 and 13) were represented. The average age for the sample was 4.2 years. The standard deviation and standard error were 1.84 and 0.09, respectively.

Comparison of Scale and Otolith Ages — We aged 423 summer flounder using both their scales and otoliths. There was evidence of systematic disagreement between otolith and scale ages (test of symmetry: χ^2 = 41.42, df = 24, P = 0.0021) with an average CV of 9.5%. Scale were assigned a lower age than otoliths for 21% of the fish and 24% of the time were scale assigned a higher age than otoliths (Figure 8). There was some evidence of bias between otolith and scale ages for the oldest fish in the sample (Figure 9), but this could be due to the extremely small number of fish in these age categories.

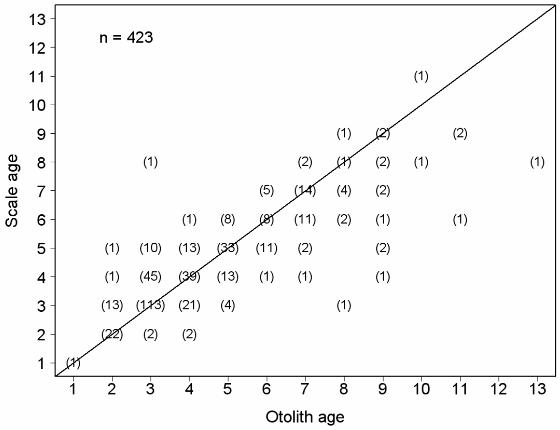


Figure 8. Comparison of scale and otolith age estimates for summer flounder in 2007

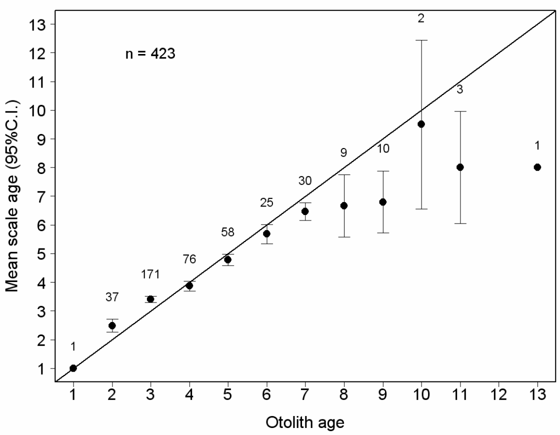


Figure 9. Age-bias plot for summer flounder scale and otolith age estimates in 2007.

Age-Length-Key — In Table 5 and Table 6, we present age-length-keys which can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using scale ages for summer flounder in Chesapeake Bay and Atlantic waters of Virginia, respectively. The tables were based on VMRC's stratified sampling of landings by total length inch intervals.

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List of Tables

Table 1. Number of summer flounder collected in the Chesapeake Bay of Virginia in 2007 and scale-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
9	5	0	0	5
10	5	0	0	5
11	5	0	0	5
12	5	0	0	5
13	14	1	1	13
14	69	8	8	61
15	58	17	17	41
16	49	12	12	37
17	45	5	5	40
18	36	4	4	32
19	28	5	5	23
20	18	4	4	14
21	16	16	16	0
22	11	11	11	0
23	10	11	11	0
24	5	4	4	1
25	5	1	1	4
26	5	2	2	3
27	5	0	0	5
28	5	0	0	5
Totals	399	101	101	299

Table 2. Number of summer flounder collected in Atlantic waters of Virginia in 2007 and scale-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
9	5	0	0	5
10	5	0	0	5
11	5	0	0	5
12	5	0	0	5
13	14	18	14	0
14	40	175	41	0
15	62	218	66	0
16	63	160	63	0
17	52	130	52	0
18	33	112	40	0
19	22	66	26	0
20	21	66	27	0
21	14	60	18	0
22	17	42	18	0
23	16	63	24	0
24	14	38	16	0
25	14	21	15	0
26	8	11	11	0
27	5	3	3	2
28	5	4	4	1
29	5	1	1	4
Totals	425	1188	439	27

Table 3. The number of summer flounder assigned to each total length-at-age category for 101 fish sampled for scale age determination in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years)								
	1	2	3	4	5	6	7	8	Totals
13	0	0	1	0	0	0	0	0	1
14	1	1	4	1	1	0	0	0	8
15	0	3	10	1	3	0	0	0	17
16	0	3	4	4	1	0	0	0	12
17	0	0	3	2	0	0	0	0	5
18	0	0	3	1	0	0	0	0	4
19	0	1	3	0	0	1	0	0	5
20	0	0	1	1	0	2	0	0	4
21	0	0	5	5	4	2	0	0	16
22	0	0	1	2	8	0	0	0	11
23	0	0	0	2	3	2	3	1	11
24	0	0	0	1	2	1	0	0	4
25	0	0	0	0	1	0	0	0	1
26	0	0	0	1	0	0	1	0	2
Totals	1	8	35	21	23	8	4	1	101

Table 4. The number of summer flounder assigned to each total length-at-age category for 101 fish sampled for scale age determination in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years) 2	3	4	5	6	7	8	9	10	11	Totals
13	5	7	2	0	0	0	0	0	0	0	14
14	14	18	8	1	0	0	0	0	0	0	41
15	8	39	16	3	0	0	0	0	0	0	66
16	2	31	23	6	0	1	0	0	0	0	63
17	1	23	18	8	2	0	0	0	0	0	52
18	1	20	10	7	2	0	0	0	0	0	40
19	0	3	10	11	1	0	1	0	0	0	26
20	0	2	6	16	2	1	0	0	0	0	27
21	0	0	6	4	3	3	2	0	0	0	18
22	0	0	0	7	4	4	3	0	0	0	18
23	0	0	3	4	5	6	3	2	1	0	24
24	0	0	0	2	2	4	6	2	0	0	16
25	0	0	0	2	6	7	0	0	0	0	15
26	0	0	0	2	2	4	1	1	0	1	11
27	0	0	0	0	0	0	1	2	0	0	3
28	0	0	0	0	1	1	1	1	0	0	4
29	0	0	0	0	0	0	0	1	0	0	1
Totals	31	143	102	73	30	31	18	9	1	1	439

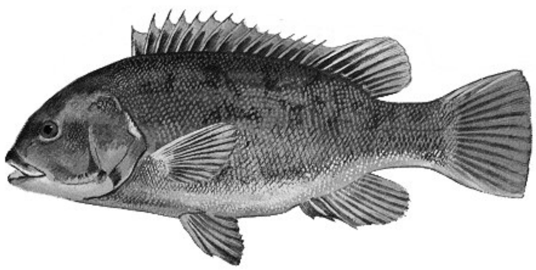
Table 5. Age-Length key, as propostion-at-age in each 1-inch length interval, based on scale ages for summer flounder sampled in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years) 1	2	3	4	5	6	7	8
13	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000
14	0.125	0.125	0.500	0.125	0.125	0.000	0.000	0.000
15	0.000	0.176	0.588	0.059	0.176	0.000	0.000	0.000
16	0.000	0.250	0.333	0.333	0.083	0.000	0.000	0.000
17	0.000	0.000	0.600	0.400	0.000	0.000	0.000	0.000
18	0.000	0.000	0.750	0.250	0.000	0.000	0.000	0.000
19	0.000	0.200	0.600	0.000	0.000	0.200	0.000	0.000
20	0.000	0.000	0.250	0.250	0.000	0.500	0.000	0.000
21	0.000	0.000	0.312	0.312	0.250	0.125	0.000	0.000
22	0.000	0.000	0.091	0.182	0.727	0.000	0.000	0.000
23	0.000	0.000	0.000	0.182	0.273	0.182	0.273	0.091
24	0.000	0.000	0.000	0.250	0.500	0.250	0.000	0.000
25	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.500	0.000	0.000	0.500	0.000

Table 6. Age-Length key, as propostion-at-age in each 1-inch length interval, based on scale ages for summer flounder sampled in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years)									
	2	3	4	5	6	7	8	9	10	11
13	0.357	0.500	0.143	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.341	0.439	0.195	0.024	0.000	0.000	0.000	0.000	0.000	0.000
15	0.121	0.591	0.242	0.045	0.000	0.000	0.000	0.000	0.000	0.000
16	0.032	0.492	0.365	0.095	0.000	0.016	0.000	0.000	0.000	0.000
17	0.019	0.442	0.346	0.154	0.038	0.000	0.000	0.000	0.000	0.000
18	0.025	0.500	0.250	0.175	0.050	0.000	0.000	0.000	0.000	0.000
19	0.000	0.115	0.385	0.423	0.038	0.000	0.038	0.000	0.000	0.000
20	0.000	0.074	0.222	0.593	0.074	0.037	0.000	0.000	0.000	0.000
21	0.000	0.000	0.333	0.222	0.167	0.167	0.111	0.000	0.000	0.000
22	0.000	0.000	0.000	0.389	0.222	0.222	0.167	0.000	0.000	0.000
23	0.000	0.000	0.125	0.167	0.208	0.250	0.125	0.083	0.042	0.000
24	0.000	0.000	0.000	0.125	0.125	0.250	0.375	0.125	0.000	0.000
25	0.000	0.000	0.000	0.133	0.400	0.467	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.182	0.182	0.364	0.091	0.091	0.000	0.091
27	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.667	0.000	0.000
28	0.000	0.000	0.000	0.000	0.250	0.250	0.250	0.250	0.000	0.000
29	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000

Chapter 12
Tautog



Tautoga onitis

INTRODUCTION

A total of 241 tautog, *Tautoga onitis*, were collected by the VMRC's Biological Sampling Program for age and growth analysis in 2007. We aged 237 fish using their opercula and we were not able to age 4 fish due to the damage of their opercula. Of 237 fish aged, 193 and 44 fish were collected in Chesapeake Bay (bay fish) and Atlantic waters (ocean fish) of Virginia, respectively. The average age for the bay fish was 4.5 years with a standard deviation of 1.9 and a standard error of 0.14. Eleven age classes (2 to 10, 13, and 14) were represented in the bay fish, comprising fish from the 1993, 1994, and 1997-2005 year classes. The 2003 and 2004 year classes were dominant in the bay fish sample in 2007. The average age for the ocean fish was 7.3 years with a standard deviation of 4.08 and a standard error of 0.62. Thirteen age classes (2 to 11, 16, 18, and 21) were represented in the ocean fish, comprising fish from the 1986, 1989, 1991, 1996 to 2005 year classes. The 2001-2002 year classes were dominant in the ocean fish sample in 2007. We also aged a total of 226 fish using their otoliths additional to ageing the opercula. The otolith ages were compared to the operculum ages to examine how close both ages were (please see details in Results).

METHODS

Sample size for ageing — We estimated sample sizes for ageing tautog collected in both Chesapeake Bay and Atlantic waters of Virginia in 2007, respectively, using a two-stage random sampling method (Quinn and Deriso 1999) in order to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing tautog in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of tautog collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of tautog used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths and opercula were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and each fish assigned a unique Age and Growth Laboratory sample number. All otoliths were stored in their original VMRC coin envelopes, while opercula were stored frozen in their original coin envelopes until processed.

Preparation —

Opercula – Tautog opercula were boiled for several minutes to remove any attached skin and muscle tissue. After boiling, opercula were examined to determine whether they were collected whole or in some way damaged. Opercula were allowed to dry and finally stored in new labeled coin envelopes.

Otoliths – Because of the small size of a tautog otolith, it required extra steps in preparation for ageing. An otolith was first baked in a Thermolyne 1400 furnace at 400°C for one to two minutes until it turned a medium brown color (caramel). The location of the core of the otolith was marked with a felt pen and the entire otolith was embedded in Loctite 349 adhesive, placed under UV light, and allowed to harden overnight. The otolith was then transversely sectioned through the felt pen mark with a low speed Buehler Isomet low-speed saw equipped with two, three-inch Norton diamond-wheel wafering blades separated by a 0.4 mm steel spacer. Completed sections were transferred to labeled standard microscope slides and covered in a thin layer of Flo-texx mounting medium to increase light transmission through the translucent zones and provide enhanced contrast and greater readability.

Readings — Opercula were aged on a light table with no magnification (Figure 1). Sectioned otoliths were aged by two different readers using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 2).

Figure 1. Operculum from a 13 year-old male tautog.

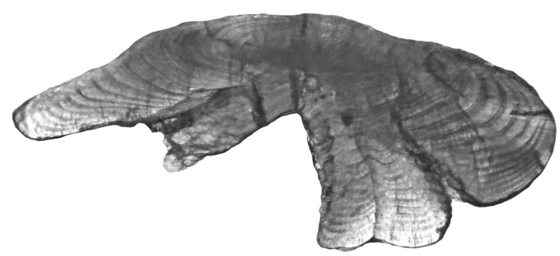


Figure 2. Otolith section from a 13 year-old male tautog. Same fish as Figure 1.

Two different readers aged all samples in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using the coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 367 for ageing the bay tautog in 2007, ranging in length interval from 8 to 30 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 8% for age 3 and the largest CV of 21% for age 1 and 6 of the bay fish. We aged 193 of 197 tautog collected by VMRC in 2007, and we were not able to age 4 fish due to their operculum damage. We were short of 175 fish from among almost all length intervals (Table 1), which could significantly decrease precision for the estimates of major ages.

We estimated a sample size of 399 for ageing the ocean tautog in 2007, ranging in length interval from 8 to 30 inches (Table 2). This sample size provided a range in CV for age composition approximately from the smallest CV of 9% for age 5 and the largest CV of 25% for age 2 and 9 of the ocean fish. We aged all 44 fish collected by VMRC in 2007. We were short of 355 fish in total in all the length intervals, as a result, the precision for the estimates of all age groups would be influenced significantly. Apparently, we did not have a good year for both bay and ocean tautog in 2007.

Opercula — Measurements of reader self-precision were fair for Reader 1 (CV = 4.7%) and poor for Reader 2 (CV = 11.4%). There was evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 36.24$, df = 21, P =0.0205). In Figure 3 we present a graph of the results for between-reader operculum ageing precision. The average between-reader coefficient of variation (CV) of 7.3% was relatively high but as the same as in 2006. The between-reader agreement for operculum for one year or less was 92% of all aged fish. The high agreement between the readers and the high CVs were partially due to the sample dominated by younger fish.

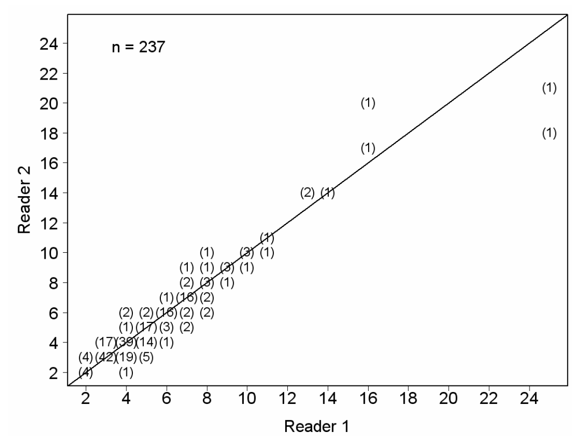


Figure 3. Between-reader comparison of operculum age estimates for tautog in 2007.

Of the 193 bay fish aged with opercula, 11 age classes (2 to 10, 13, and 14) were represented (Table 3). The average operculum age was 4.5 years, and the standard deviation and standard error were 1.9 and 0.14, respectively. Year-class data (Figure 4) indicate that recruitment into the fishery in Chesapeake Bay occurred at age 2, which corresponds to the 2005 year-class for tautog caught in 2007. Year-class abundance was high for the 2003–2004 year-classes.

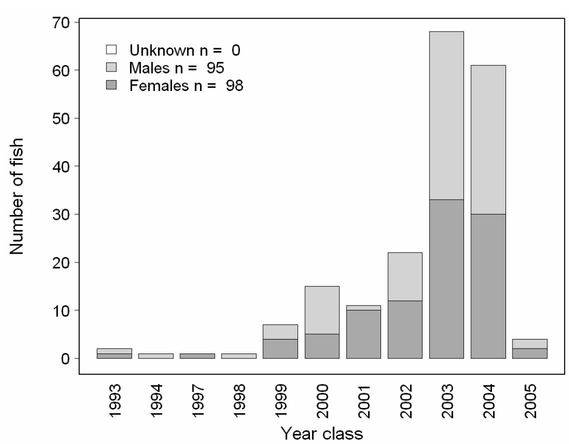


Figure 4. Year-class frequency distribution for tautog collected in Chesapeake Bay of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using operculum ages. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Of the 44 ocean fish aged with opercula, 13 age-classes (2 to 11, 16, 18, and 21) were represented (Table 4). The average operculum age was 7.3 years, and the standard deviation and standard error were 4.08 and 0.62 respectively. Year-class data (Figure 5) indicate that recruitment into the fishery in Atlantic waters of Virginia began at age 2, which corresponds to the 2005 year-class for summer flounder caught in 2007. The 2001-2002 year class was dominant in the sample.

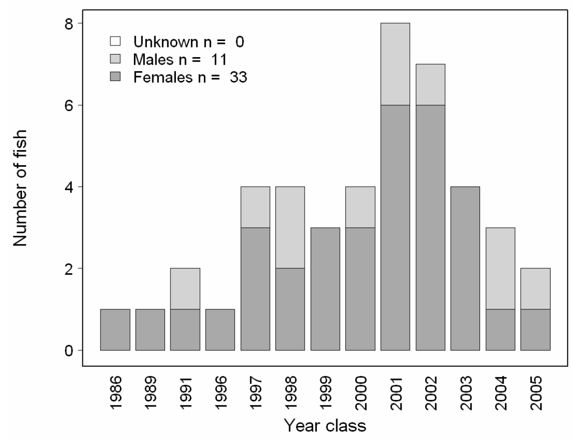


Figure 5. Year-class frequency distribution for tautog collected in Atlantic waters of Virginia for ageing in 2007. Distribution is broken down by sex and estimated using operculum ages. "Unknown" sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Otoliths — Measurements of reader self-precision were good, with both readers able to reproduce the ages of previously read otoliths (Reader 1's CV = 2.9% and Reader 2's CV = 2.1%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 17.09$, df = 15, P = 0.3138). In Figure 6 we present a graph of the results for between-reader otolith ageing precision. The average between-reader coefficient of variation (CV) of 2% was not significant and similar to the CV of 1.7% in 2006. The between-reader agreement for otoliths was 86% of all aged fish.

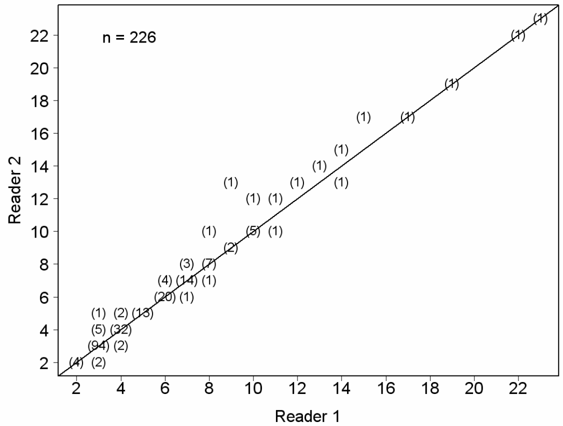


Figure 6. Between-reader comparison of otolith age estimates for tautog in 2007.

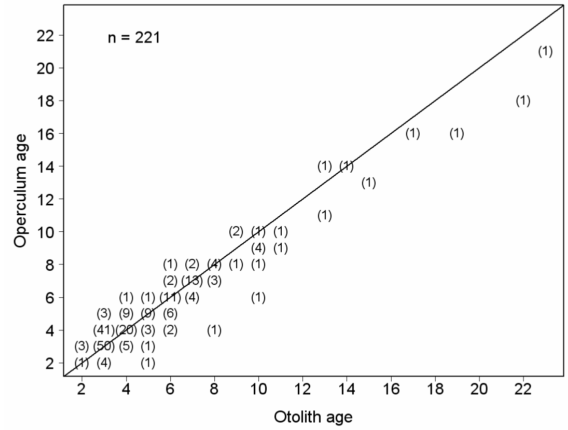


Figure 7. Comparison of operculum and otolith age estimates for tautog in 2007.

Of the 226 fish aged with otoliths, 17 age-classes (2 through 15, 17, 19, 22, and 23) were represented. The average age for the sample was 5 years. The standard deviation and standard error were 3.17 and 0.21, respectively.

Comparison of Operculum and Otolith Ages — we aged 221 tautog using both their opercula and otoliths. There was evidence of systematic disagreement between otolith and operculum ages (test of symmetry: $\chi^2 = 52.75$, df = 24, $P < 0.0001$) with an average CV of 9.3%. Operculum were assigned a lower age than otoliths for 20% of the fish and 30% of the time were operculum assigned a higher age than otoliths (Figure 7). There was also evidence of bias between otolith and operculum ages using an age bias plot (Figure 8), again with operculum generally assigned higher ages for younger fish and lower ages for older fish than otoliths age estimates.

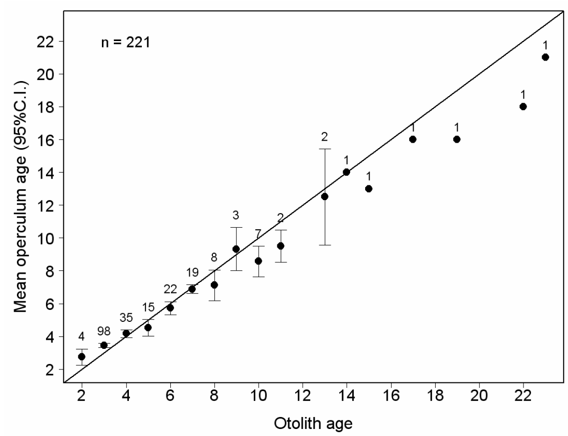


Figure 8. Age-bias plot for tautog operculum and otolith age estimates in 2007.

Age-Length-Key — In Table 5 and Table 6 we present age-length-keys which can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using operculum ages for summer flounder in Chesapeake Bay and Atlantic waters of Virginia, respectively.. The tables were based on VMRC's stratified sampling of landings by total length inch intervals.

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List of Tables

Table 1. Number of tautog collected in the Chesapeake Bay of Virginia in 2007 and operculum-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
8	5	0	0	5
9	5	0	0	5
10	4	0	0	4
11	8	0	0	8
12	8	1	1	7
13	46	27	27	19
14	70	51	50	20
15	55	35	34	21
16	41	28	27	14
17	34	26	25	9
18	22	8	7	15
19	12	11	11	1
20	7	2	3	4
21	5	6	6	0
22	5	0	0	5
23	5	0	0	5
24	5	2	2	3
25	5	0	0	5
26	5	0	0	5
27	5	0	0	5
28	5	0	0	5
29	5	0	0	5
30	5	0	0	5
Totals	367	197	193	175

Table 2. Number of tautog collected in Atlantic waters of Virginia in 2007 and operculum-aged in each 1-inch length interval. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Interval	Target	Collected	Aged	Need
8	5	0	0	5
9	5	0	0	5
10	5	0	0	5
11	11	1	1	10
12	8	0	0	8
13	49	1	1	48
14	56	5	5	51
15	52	4	4	48
16	47	4	4	43
17	36	4	4	32
18	29	5	5	24
19	18	4	4	14
20	18	1	1	17
21	11	3	3	8
22	7	6	6	1
23	7	0	0	7
24	5	0	0	5
25	5	4	4	1
26	5	0	0	5
27	5	2	2	3
28	5	0	0	5
29	5	0	0	5
30	5	0	0	5
Totals	399	44	44	355

Table 3. The number of tautog assigned to each total length-at-age category for 193 fish sampled for operculum age determination in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years) 2	3	4	5	6	7	8	9	10	13	14	Totals
12	0	1	0	0	0	0	0	0	0	0	0	1
13	3	16	8	0	0	0	0	0	0	0	0	27
14	0	26	21	2	1	0	0	0	0	0	0	50
15	0	14	15	5	0	0	0	0	0	0	0	34
16	1	4	15	4	2	1	0	0	0	0	0	27
17	0	0	6	10	6	2	1	0	0	0	0	25
18	0	0	2	1	2	1	1	0	0	0	0	7
19	0	0	1	0	0	6	3	0	0	0	1	11
20	0	0	0	0	0	2	1	0	0	0	0	3
21	0	0	0	0	0	3	1	0	1	0	1	6
24	0	0	0	0	0	0	0	1	0	1	0	2
Totals	4	61	68	22	11	15	7	1	1	1	2	193

Table 4. The number of tautog assigned to each total length-at-age category for 44 fish sampled for operculum age determination in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years													
	2	3	4	5	6	7	8	9	10	11	16	18	21	Totals
11	1	0	0	0	0	0	0	0	0	0	0	0	0	1
13	1	0	0	0	0	0	0	0	0	0	0	0	0	1
14	0	1	1	3	0	0	0	0	0	0	0	0	0	5
15	0	1	1	2	0	0	0	0	0	0	0	0	0	4
16	0	1	1	1	1	0	0	0	0	0	0	0	0	4
17	0	0	0	0	2	2	0	0	0	0	0	0	0	4
18	0	0	1	1	3	0	0	0	0	0	0	0	0	5
19	0	0	0	0	2	0	1	1	0	0	0	0	0	4
20	0	0	0	0	0	1	0	0	0	0	0	0	0	1
21	0	0	0	0	0	1	0	2	0	0	0	0	0	3
22	0	0	0	0	0	0	2	1	3	0	0	0	0	6
25	0	0	0	0	0	0	0	0	1	1	1	0	1	4
27	0	0	0	0	0	0	0	0	0	0	1	1	0	2
Totals	2	3	4	7	8	4	3	4	4	1	2	1	1	44

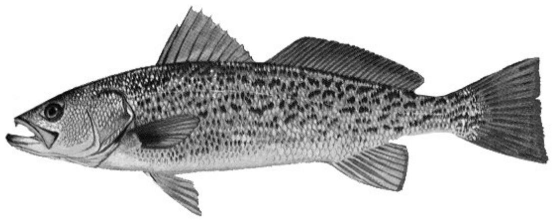
Table 5. Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for tautog sampled in Chesapeake Bay of Virginia during 2007.

Length 1-inch interval	Age (years)										
	2	3	4	5	6	7	8	9	10	13	14
12	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.111	0.593	0.296	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.520	0.420	0.040	0.020	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.412	0.441	0.147	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.037	0.148	0.556	0.148	0.074	0.037	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.240	0.400	0.240	0.080	0.040	0.000	0.000	0.000	0.000
18	0.000	0.000	0.286	0.143	0.286	0.143	0.143	0.000	0.000	0.000	0.000
19	0.000	0.000	0.091	0.000	0.000	0.545	0.273	0.000	0.000	0.000	0.091
20	0.000	0.000	0.000	0.000	0.000	0.667	0.333	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.500	0.167	0.000	0.167	0.000	0.167
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000	0.500	0.000

Table 6. Age-Length key, as proportion-at-age in each 1-inch length interval, based on operculum ages for tautog sampled in Atlantic waters of Virginia during 2007.

Length 1-inch interval	Age (years) 2	3	4	5	6	7	8	9	10	11	16	18	21
11	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.200	0.200	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.250	0.250	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.250	0.250	0.250	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.200	0.200	0.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.500	0.000	0.250	0.250	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.667	0.000	0.000	0.000	0.000	0.000
22	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.167	0.500	0.000	0.000	0.000	0.000
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.250	0.250	0.250	0.000	0.250
27	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.500	0.000

Chapter 13
Weakfish



Cynoscion regalis

INTRODUCTION

We aged 422 weakfish, *Cynoscion regalis*, collected by the VMRC's Stock Assessment Program for age and growth analysis in 2007. The weakfish ages ranged from 1 to 6 years old with an average age of 2.7, a standard deviation of 1.02, and a standard error of 0.05. Six age classes (1 to 6) were represented, comprising fish from the 2001 through 2006 year-classes, with fish primarily from the 2005 year-classes.

METHODS

Sample size for ageing — We estimated sample size for ageing weakfish in 2007 using a two-stage random sampling method (Quinn and Deriso 1999) to increase precision in estimates of age composition from fish sampled efficiently and effectively. The basic equation is:

$$A = \frac{V_a}{\theta_a^2 CV^2 - B_a / L}, \qquad (1)$$

where A is the sample size for ageing weakfish in 2007; θ_a stands for the proportion of age a fish in a catch. V_a and B_a represent variance components within and between length intervals for age a, respectively; CV is coefficient of variance; L is a subsample from a catch and used to estimate length distribution in the catch. θ_a, V_a, B_a, and CV were calculated using pooled age-length data of weakfish collected from 1999 to 2005 and using equations in Quinn and Deriso (1999). For simplicity, the equations are not listed here. L was the total number of weakfish used by VMRC to estimate length distribution of the caches from 1999 to 2005. The equation (1) indicates that the more fish is aged, the smaller CV (or higher precision) will be obtained. Therefore, the criterion to decide A is that A should be a number above which there is only a 1% CV reduction achieved by aging an additional 100 or more fish.

Handling of collection — Otoliths were received by the Age & Growth Laboratory in labeled coin envelopes. Once in our hands, they were sorted based on date of capture, their envelope labels were verified against VMRC's collection data, and assigned unique Age and Growth Laboratory sample numbers. All otoliths were stored dry in their original VMRC coin envelopes.

Preparation — Otoliths were processed following the methods described in Barbieri et al. (1994) with a few modifications. Briefly, the left or right sagittal otolith was randomly selected and attached to a glass slide with Electron Microscopy Sciences' clear Crystalbond™ 509 adhesive. At least one transverse cross-section was cut through the core of each otolith using a Buehler Isomet low-speed saw equipped with two, three inch, fine- grit Norton diamond-wheel wafering blades, separated by a spacer of 0.3mm. Otolith sections were placed on labeled glass slides and covered with a thin layer of Flo-texx mounting medium that not only adhered the sections to the slide, but, more importantly, provided enhanced contrast and greater readability by increasing light transmission through the sections.

Readings — Two different readers aged all sectioned otoliths using a Leica MZ-12 stereo microscope with transmitted light and dark-field polarization at between 8 and 100 times magnification (Figure 1). Each reader aged all of the otolith sections using ageing criteria listed in Lowerre-Barbieri et al. (1994). All samples were aged in chronological order based on collection date, without knowledge of previously estimated ages or the specimen lengths. When the readers' ages agreed, that age was assigned to the fish. When the two readers disagreed, both readers sat down together and re-aged the fish, again without any knowledge of previously estimated ages or lengths, and assigned a final age to the fish. When the readers were unable to agree on a final age, the fish was excluded from further analysis.

Figure 1. Sectioned otolith of a female weakfish with 6 annuli

Comparison Tests — A random sub-sample of 50 fish was selected for second readings to measure within-reader precision and age reproducibility using coefficient of variance (CV). Age estimates from Reader 1 were plotted against age estimates from Reader 2 to assess deviation from 1:1 equivalence (Campana et al. 1995).

RESULTS

We estimated a sample size of 434 for ageing weakfish in 2007, ranging in length interval from 6 to 34 inches (Table 1). This sample size provided a range in CV for age composition approximately from the smallest CV of 6% for age 2 and the largest CV of 15% for age 5 fish. In 2007, we randomly selected and aged 422 fish from 848 weakfish collected by VMRC. We had fewer than 51 fish mainly from the very large and small length intervals (Table 1), therefore, the precision for the estimates of major age groups (such as age 2 and 3) would not be influenced significantly.

The measurement of reader self-precision was high for both readers (Reader 1's CV = 1.2% and Reader 2's CV = 0.4%). There was no evidence of systematic disagreement between Reader 1 and Reader 2 (test of symmetry: $\chi^2 = 3$, df = 3, $P = 0.3916$). Figure 2 illustrates that the between-readers' precision of age estimates with an average CV of 0.1% was not significant with an agreement of 99% between two readers.

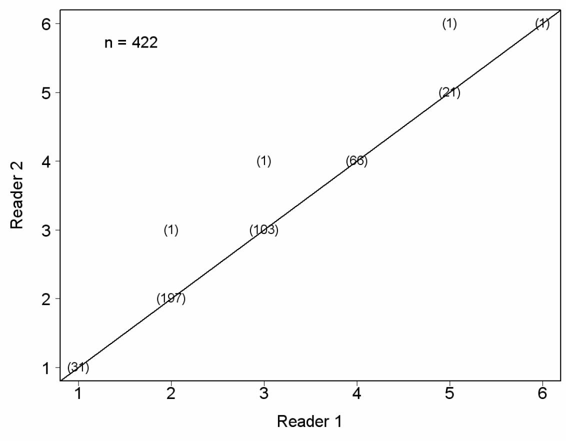


Figure 2. Between-reader comparison of otolith age estimates for weakfish in 2007

Of the 422 fish aged with otoliths, 6 age classes were represented (Table 2). The average age was 2.7 years old, and the standard deviation and standard error were 1.02 and 0.05, respectively.

Year-class data (Figure 3) shows that the fishery was comprised of 6 year-classes, comprising fish from the 2001-2006 year-classes, with fish primarily from the 2005 year-classes. The females were highly dominant in the sample collected in 2007

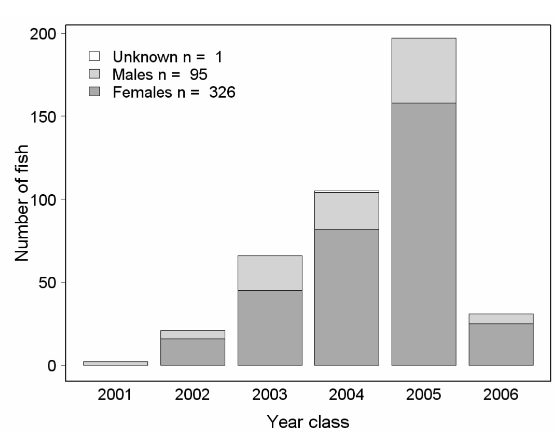


Figure 3. Year-class frequency distribution for weakfish collected for ageing in 2007. Distribution is broken down by sex. "Unknown sex individuals were either juveniles or had damaged gonads (sex indeterminable).

Age-Length-Key — In Table 3 we present an age-length-key that can be used in the conversion of numbers-at-length in the estimated catch to numbers-at-age using otolith ages. The table is based on VMRC's stratified sampling of landings by total length inch intervals.

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List of Tables

Table 1. Number of weakfish collected, and aged in each 1-inch length interval in 2007. Target represents the sample size for ageing estimated for 2007, and Need represents number of fish shorted in each length interval compared to the optimum sample size for ageing and number of fish aged.

Length 1-inch Interval	Target	Collected	Aged	Need
6	5	1	1	4
7	5	4	4	1
8	6	21	11	0
9	32	163	59	0
10	76	152	77	0
11	57	106	58	0
12	41	64	42	0
13	29	82	31	0
14	22	53	22	0
15	19	33	19	0
16	14	32	15	0
17	10	17	10	0
18	11	30	11	0
19	9	20	10	0
20	12	20	12	0
21	11	18	11	0
22	10	12	10	0
23	8	9	8	0
24	6	3	3	3
25	6	4	4	2
26	5	3	3	2
27	5	1	1	4
28	5	0	0	5
29	5	0	0	5
30	5	0	0	5
31	5	0	0	5
32	5	0	0	5
33	5	0	0	5
34	5	0	0	5
Totals	434	848	422	51

Table 2. The number of weakfish assigned to each total length-at-age category for 422 fish sampled for otolith age determination in Virginia during 2007.

Length 1-in interval	Age (years) 1	2	3	4	5	6	Totals
6	1	0	0	0	0	0	1
7	4	0	0	0	0	0	4
8	6	5	0	0	0	0	11
9	4	47	8	0	0	0	59
10	4	47	26	0	0	0	77
11	3	24	28	2	1	0	58
12	7	19	12	4	0	0	42
13	0	21	5	4	1	0	31
14	1	13	5	3	0	0	22
15	1	8	7	3	0	0	19
16	0	6	3	6	0	0	15
17	0	2	1	6	1	0	10
18	0	1	3	7	0	0	11
19	0	1	2	7	0	0	10
20	0	1	2	5	4	0	12
21	0	2	2	1	5	1	11
22	0	0	1	5	4	0	10
23	0	0	0	3	4	1	8
24	0	0	0	2	1	0	3
25	0	0	0	4	0	0	4
26	0	0	0	3	0	0	3
27	0	0	0	1	0	0	1
Totals	31	197	105	66	21	2	422

Table 3. Age-Length key, as propostion-at-age in each 1-inch length interval, based on otolith ages for weakfish sampled for age determination in Virginia during 2007

Length 1-in interval	Age (years) 1	2	3	4	5	6
6	1.000	0.000	0.000	0.000	0.000	0.000
7	1.000	0.000	0.000	0.000	0.000	0.000
8	0.545	0.455	0.000	0.000	0.000	0.000
9	0.068	0.797	0.136	0.000	0.000	0.000
10	0.052	0.610	0.338	0.000	0.000	0.000
11	0.052	0.414	0.483	0.034	0.017	0.000
12	0.167	0.452	0.286	0.095	0.000	0.000
13	0.000	0.677	0.161	0.129	0.032	0.000
14	0.045	0.591	0.227	0.136	0.000	0.000
15	0.053	0.421	0.368	0.158	0.000	0.000
16	0.000	0.400	0.200	0.400	0.000	0.000
17	0.000	0.200	0.100	0.600	0.100	0.000
18	0.000	0.091	0.273	0.636	0.000	0.000
19	0.000	0.100	0.200	0.700	0.000	0.000
20	0.000	0.083	0.167	0.417	0.333	0.000
21	0.000	0.182	0.182	0.091	0.455	0.091
22	0.000	0.000	0.100	0.500	0.400	0.000
23	0.000	0.000	0.000	0.375	0.500	0.125
24	0.000	0.000	0.000	0.667	0.333	0.000
25	0.000	0.000	0.000	1.000	0.000	0.000
26	0.000	0.000	0.000	1.000	0.000	0.000
27	0.000	0.000	0.000	1.000	0.000	0.000

Chapter 14

Sheepshead

Archosargus probatocephalus

INTRODUCTION

During 2008, a total of 82 sheepshead, Archosargus probatocephalus, were collected and aged, giving us a 3 year total of 472 fish collected and aged. These 472 sheepshead ranged in age from 0 (young-of-the-year; YOY) to 35 years old with an average age of 7.5, a standard deviation of 7.2, and a standard error of 0.33 years. Further, sheepshead representing thirty-three age classes (0 to 26, 29, 30, and 32 to 35), comprising twenty-nine year classes (1973, 1974, 1977, and 1983-2007) were observed. In the total sample, the 2007 year-class was dominant (28%), followed by the year classes of 1997 (12%) and 2001(12%). With regards to growth, the sheepshead of Chesapeake Bay grew very rapidly up to 5 years-of-age, but by age 10, growth had begun to slow. Further, in general, their growth was faster and they obtained larger maximum sizes than sheepshead from South Carolina, Florida, and Louisiana. Macroscopic gonad inspection and histological staining suggests that sheepshead in Chesapeake Bay are multiple batch spawners from June to August.

In conclusion, the presence of YOY, faster growth rates, and local spawning activity suggest the sheepshead of Chesapeake Bay are indeed a local population that are governed by their unique vital rates and population dynamics. Further, based on the preliminary data obtained over the past 3 years, in December 2007 we recommended a minimum length limit of 20 inches be implemented, with a target fishing mortality rate (F) for the recreational and commercial fisheries combined between 0.131 and 0.196.

METHODS

1. Field work

1) Recreational sampling
In 2008, we continued to work with recreational anglers closely. As in 2007, coolers were distributed to the same four marinasand brochures were distributed to promote the project. The Marina at Marina Shores and Long Bay Pointe Marina both allowed the coolers to remain on site and volunteered to check coolers daily for the presence of sheepshead. The two remaining marinas, Taylor’s Landing and Little Creek Marina, had coolers on site on weekends and major holidays.

Further, to increase the sample size, we hired a charter boat for five days to collect sheepshead during the summer of 2008. In addition, Center for Quantitative Fisheries Ecology (CQFE)staff undertook several trips with local recreational hook-and-line anglers and spearfishers to collect sheepshead

2) Commercial sampling
In 2008, we collected sheepshead from commercial fisheries with the help of the Virginia Marine Resources Commission (VMRC). VMRC employees sampled the commercial sectors daily and collected all the sheepshead they intercepted for us.

3) Independent sampling
Because most of the sheepshead we collected from the recreational and commercial fisheries were larger than 21 in. and greater than 4 years old in 2006 and 2007, we continued to try and collect small juvenile sheepshead from mid to lower bay seagrass beds in 2008. We collaborated with the Virginia Institute of Marine Sciences (VIMS) and other members of the Center for Quantitative Fisheries Ecology to collect any sheepshead encountered while trawling for spotted seatrout (*Cynoscion nebulosus*) on seagrass beds during the summer and fall.

2. Lab work

Once collected, we brought the sheepshead back to CQFE where they were immediately processed in the lab. Weights and lengths (total length (TL), fork length (FL), and standard length (SL)) were recorded to the nearest 0.0001 pounds (lbs; 0.5 grams) and 1 millimeter (mm; 0.04 inches), respectively. In addition, we removed their sagittal otoliths for aging and female gonads for histological examination and determination of annual total fecundity. Finally, we removed scales and pelvic spines, took muscle tissue samples, and preserved their stomachs for use in other studies on sheepshead of the Chesapeake Bay.

To age each individual, we mounted an otolith from each fish to a microscope slide. Subsequently, the otolith was sectioned using a Buehler Isomet saw equipped with two Norton diamond wafering blades separated by a 0.4 mm stainless steel spacer, positioned so that the wafering blades straddled the core of the otolith. This produces an otolith transverse section that is used for aging. We then placed each section on a labeled glass slide and covered it with a thin layer of Flo-texx mounting medium (Figure 1).

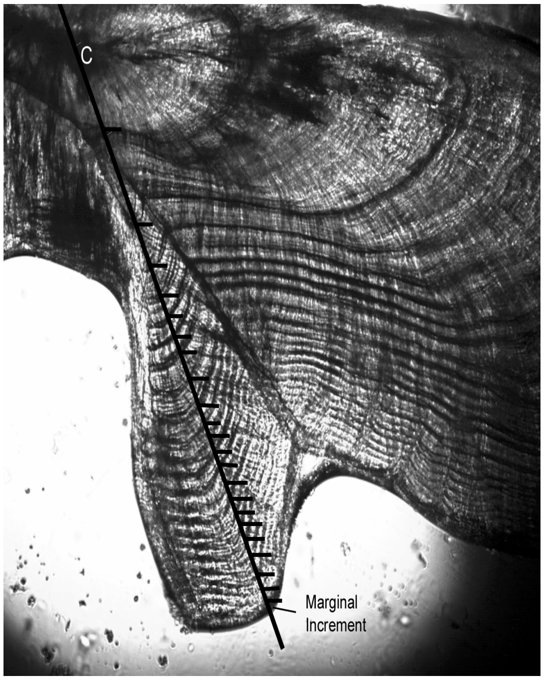

Figure 1. Thin-sectioned otolith from a 22-yr old sheepshead showing the core (C) of the otolith, the measuring axis with annuli marked, and the marginal increment or growth on the edge of the otolith.

Before preserving the gonads in formalin, staff e macroscopically evaluated the maturity of females usin a 1 to 5 staging scale. Female stages 1 to 5 are defined as follows:

1) Ovaries are small and tubular with many blood vessels.
2) Ovaries are large with colored liquid in them.
3) Small eggs are present and granular looking.
4) Eggs are ripe and flow freely, indicating that the fish are spawning.
5) Ovaries are large but deflated with some remaining eggs, indicating that the fish had spawned.

Further, during processing of male sheepshead, their gonads were macroscopically staged using a 1 to 4 scale. Male stages 1 to 4 are defined as follows:
1) Any fish which can be distinguished as a male; the testes will have few, if any, blood vessels and a flattened exterior side.
2) Any male with whitish testes; these usually have more form to them and are hard.
3) Any male with large white testes that have viable sperm (when the testes are cut, the milt will flow out).
4) Any male with large deflated testes, there may be some sperm remaining, and an increase in blood vessels may occur.

After we had macroscopically staged the gonads of females, we removed and weighed the gonads to the nearest 0.1 g and preserved in 10% buffered formalin for further histological analysis. The Department of Pathobiological Sciences at Louisiana State University (LSU) helped us to make histology slides for histological analysis (microscopic analysis). Before we sent the ovaries to LSU, they were prepared as follows:

i) Select a portion of the ovaries (usually the middle portion) and slice a cube about 1 x 1 x 1 cm.
ii) Rinse the sample with tap water 3 times, for 30 minutes each.
iii) Transfer the sample from the final tap water rinse to 70% Ethanol in a 50-ml glass jar and seal it with the cap.

3. Age determination

Using polarized light and an image analysis system, we aged the otoliths, without prior knowledge of fish length, by counting individual annuli (Figure 1). To confirm the formation of one annulus per year, we used marginal increment analysis. Further, we incorporated procedures to establish quality assurance and reliability of age readings into our laboratory protocols. We measured precision within the primary reader and between the primary reader and the secondary reader using a one-to-one equivalence plot (Campana et al. 1995), a symmetry test (Hoenig et al. 1995), and mean coefficient of variation (CV).

Due to the small sample sizes from individual years, we developed a year-specific age-length-key (ALK) using otolith ages pooled from 2006 to 2008.

4. Growth model development

To develop von-Bertalanffy growth models for sheepshead in Chesapeake Bay, we first developed von-Bertalanffy growth models for each sex for each year. Subsequently, using Kimura's likelihood ratio test (Kimura 1980), we compared the resulting sex specific growth curves with-in each year. When no significant differences were found between two sex models, a year-specific growth model was developed using sex-pooled data within each year. The year-specific models among three years were then compared using Kimura's likelihood ratio test. When no significant differences were found among the year-specific models, the male and female models were developed using year-pooled data separately. Finally, Kimura's likelihood ratio test was used to test differences between the sex-specific year-pooled growth models. If there was no significant difference, then, a sex- and year-pooled model was developed. If there was a significant difference, then, sex-specific year-pooled models were kept.

5. Sheepshead age and growth paper manuscript

During the last quarter, PhD student Joseph Ballenger has been working on constructing a manuscript regarding the age and growth of sheepshead in Chesapeake Bay based upon the combined data on sheepshead collected during 2006, 2007, and 2008. We used R statistical computing software (V2.7.2) to develop von Bertalanffy growth curves and weight-length regressions for sheepshead. These growth curves were compared to sheepshead growth curves in South Carolina, Florida, and Louisiana using Kimura's (1980) likelihood ratio test, Helser's (1996) randomization test, and a variance ratio test (Zar 1996).

6. Management strategies

Sheepshead fisheries in Chesapeake Bay of Virginia consist of both recreational and commercial sectors. Therefore, we estimated biological reference points (BRP) which would fulfill both sectors. Specifically, the BRPs attempted to allow for both a maximum yield for the yield-based commercial fishery and trophy fish for the recreational fishery while preventing the occurrence of overfishing (recruitment and growth overfishing). We used a dynamic pool model and growth parameters to estimate the maximum biomass-at-age when fishing doesn't occur. Then, a yield-per-recruit model was used to estimate a minimum length limit (MLL) and a range of target fishing mortalities (F).

RESULTS

1. Sample collection

During 2008, we collected 82 sheepshead, for a total of giving a total of 474 fish collected during the three years of the study. Of the 474 sheepsehad collected, 266 (56.1%) fish were obtained from recreational anglers, 146 (30.8%) fish from commercial fisheries, and 62 (13.1%) from fishery independent sampling. Among those fish, 131 (27.6%) were male, 184 (38.8%) were female, and 159 (33.5%) were YOY. This corresponds to a female to male ratio of 1.4:1 which is significantly different from a 1:1 sex ratio (X^2 = 8.92, df = 1, P = 0.0028). Total lengths of sheepshead collected ranged from a minimum of 0.98 in. to a maximum of 26.7 while fish weights ranged from a minimum of 0.0006 lbs. to a maximum of 19.9 lbs.

2. Age determination

We aged all 82 fish collected in 2008, making up a total of 472 sheepshead aged during the three years of the study. Two sheepshead collected in previous years were not aged due to the loss of the sagittal otoliths. The ages of the 472 sheepshead ranged from a minimum of 0 years old (YOY) to a maximum of 35 years old with an average of 7.5, a standard deviation of 7.2, and a standard error of 0.33 years. Thirty-three age classes (0 to 26, 29, 30, and 32 to 35) were represented (Table 1), comprising twenty-nine year classes (1973, 1974, 1977, and 1983-2007; Figure 2). Sheepshead from the 2007 year-class were dominant (28%), followed by individuals from the year classes of 1997 (12%) and 2001 (12%) in the three-year sample (Figure 2).

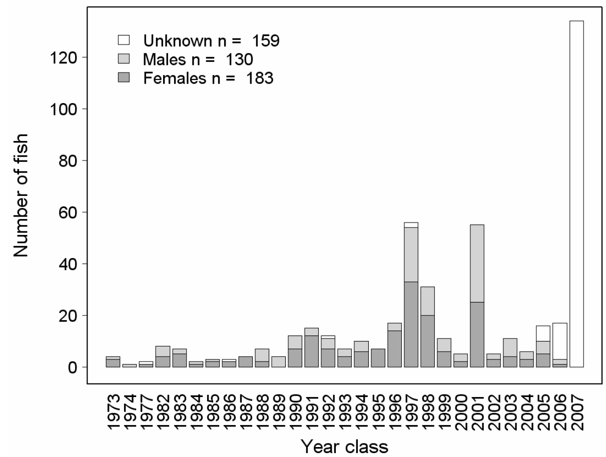

Figure 2. Year-class frequency distribution for sheepshead collected in 2006-2008. Distribution is broken down by sex.

Table 2 is an ALK developed from the age composition presented in Table 1. The ALK can be used in the conversion of number-at-length in the estimated catch to number-at-age.

There was no significant difference between the first and second readings for the primary reader (test of symmetry: χ^2 = 34.45, df = 29, P = 0.2230), and between the primary and secondary readers (test of symmetry: χ^2 = 46.6, df = 34, P = 0.0735). The average CVs were 2% and 3.4% for the primary reader and between two readers, respectively. An agreement between the first and second readings for the primary reader was 85% (**Figure** 3), and between the primary and secondary readers was 75% (**Figure 4**).

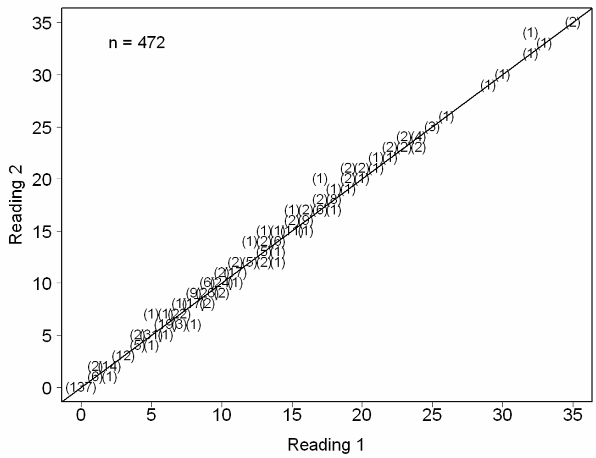

Figure 3. The primary reader's between-reading comparison of otolith age estimates for sheepshead collected in 2006-2008.

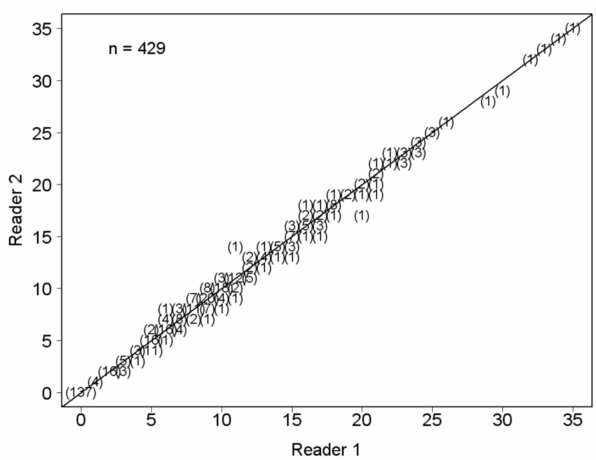

Figure 4. Between-reader comparison of otolith age estimates for sheepshead collected in 2006-2008.

3. Growth

Kimura's likelihood ratio test indicated that there were no dimorphic differences in growth rates between male and female sheepshead within each year (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.2276$ for 2006, $P = 0.4402$ for 2007, $P = 0.2142$ for 2008) and between years with the sex-pooled within each year (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.6915$ for 2006 vs. 2007, $P = 0.1981$ for 2007 vs. 2008, $P = 0.3123$ for 2006 vs. 2008). However, there was a significant difference between the male and female year-pooled growth models (H_0: $Linf_1 = Linf_2$, $k_1 = k_2$, $t_{o1} = t_{o2}$; $P = 0.0286$). Therefore, the von Bertalanffy growths were developed for each sex with the year-pooled (**Figure 5**). In general, sheepshead in Chesapeake Bay grew very rapidly before 5 years-of-age, but by age 10, growth began to slow. The female fish grew faster and were larger at age than the male.

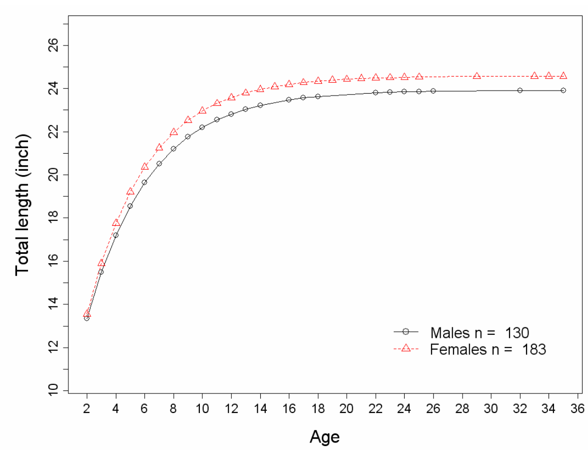

Figure 5. von Bertalanffy growths by male and female sheepshead collected in 2006-2008.

The von Bertalanffy length growth models for male and female are

$TL = 23.92 \text{ x } (1 - e^{-0.227 (t - (-1.606))})$ and

$TL = 24.58 \text{ x } (1 - e^{-0.240 (t - (-1.335))})$, respectively,

where *TL* is total length in inches and *t* is age in years.

We compared the growth of sheepshead in Chesapeake Bay to those in other areas using the pooled-year and –sex growth model of Chesapeake sheepshead. Sheepshead of Chesapeake Bay are as larger at age than sheepshead from other areas and are generally attaining larger maximum fork lengths and weights. Kimura's likelihood ratio test, Helser's randomization test, and the variance ratio test confirms this, as there are significant differences in growth rates between Chesapeake Bay sheepshead and sheepshead from South Carolina (McDonough, pers. comm.; Wenner 1996), Florida (Dutka-Gianelli and Murie 2001; MacDonald, pers. comm.; MacDonald et al. In Review; Munyandorero et al. 2006), and Louisiana (Beckman et al. 1991) in terms of their length and weight. The models for Chesapeake Bay suggests that sheepsheads are exhibiting fast growth until age 8 and 10 for length (Figure 6) and weight (**Figure 7**), respectively, after which growth begins to slow. In other areas, it appears that growth in length and weight begins to slow much earlier during the lifespan, with growth rates beginning to slow between age 4 and 8 (Figure 6 and 7). Thus, by age 10, though sheepshead in Chesapeake Bay average approximately 525 mm (21 in) FL and 4 kg (9 lbs), in other areas they are only between 350 (14 in) and 450 mm (18 in) in FL and 2 kg (4 lbs) in weight.

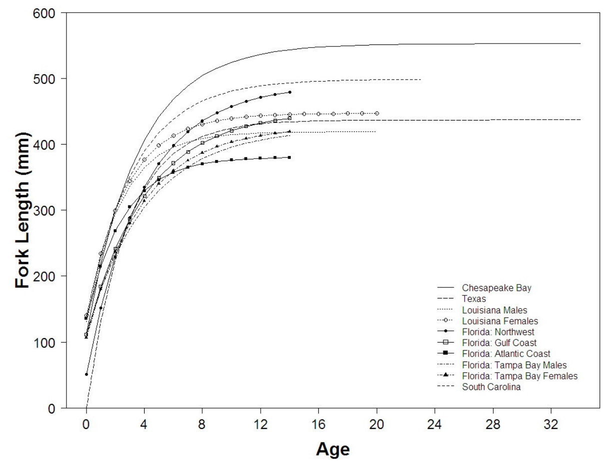

Figure 6. von Bertalanffy growth curve for Chesapeake Bay and those published for sheepshead from other areas.

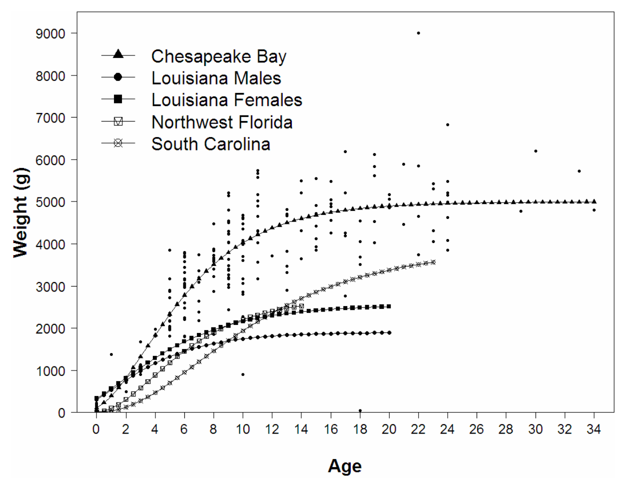

Figure 7**.** von Bertalanffy weight growth curve for Chesapeake Bay and those published from other areas.

4. Maturity and spawning season

From our collections in 2006-2008, we were able to conduct macroscopic examinations on 315 sheepshead for which we knew the date of capture. Of these, 184 were females, and 131 were males.

Mature females ranged in maturity from stage 1 to stage 5 (Figure 8). From this, we see that stage 4 fish were only collected in June and stage 5 fish were collected from June to December. However, we collected no female sheepshead in January, February, or March, and only one in April and seven in May. Collected males ranged in maturity from stage 1 to stage 4 (**Figure 9**), with male stage 3 individuals being collected in the months of June, July, and August. Thus, based on the data we have here, it is possible that the local spawning season could occur between the months of June and August. This result is supported by our collecting YOY from July through November.

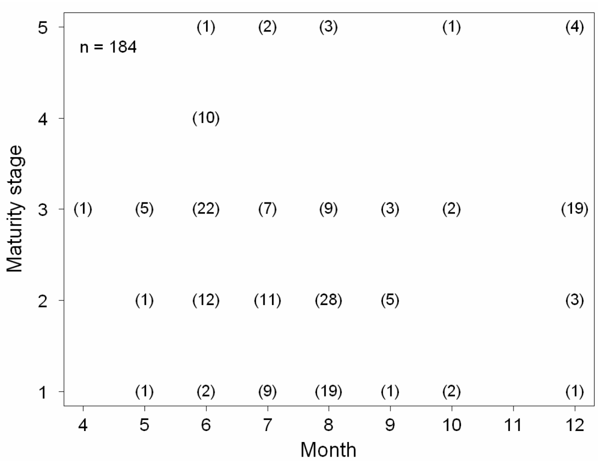

Figure 8. Maturity stages of female sheepshead collected in 2006-2008.

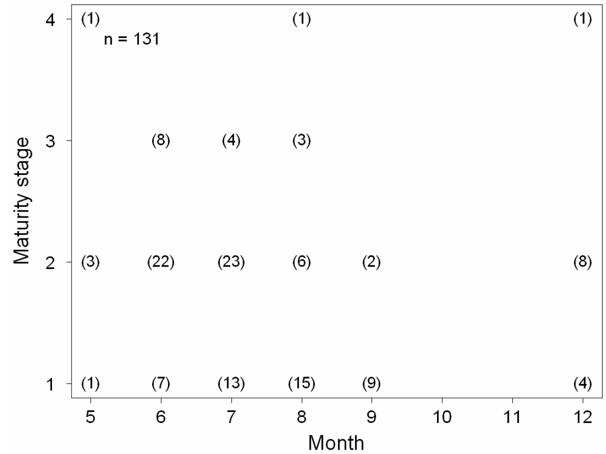

Figure 9. Maturity stages of male sheepshead collected in 2006-2008.

5. Management strategies

We found that the sheepshead in Chesapeake Bay would reach the maximum biomass at age 7 (Figure 10). The yield-per-recruit model indicated that the optimum management strategies for sheepshead of Chesapeake Bay would be a 20 in. minimum length limit with a target F_{ABC} ranging from 0.131 to 0.196 (Table 3).

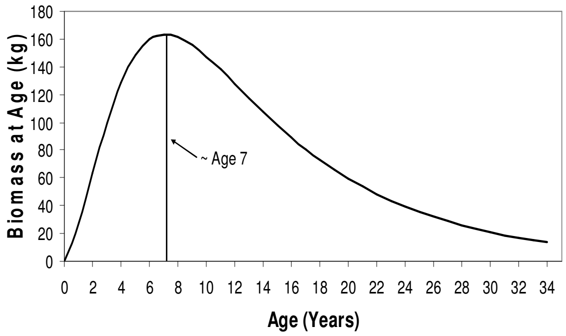

Figure 10. Biomass at age graph per 1000 individuals in the cohort entering the population for sheepshead assuming growth parameters for sheepshead from Chesapeake Bay, Virginia and a stable age distribution. Maximum biomass at age would occur at approximately age 7.

DISCUSSION

Murdy et al. (1997) reported that the sheepshead of Chesapeake Bay could live longer than 8 years, which is supported by our data, since we have found sheepshead that are up to 35 years old in the Bay, which is much older than expected previously. Further, our evidence suggests sheepshead of Chesapeake Bay are growing faster than those in southern states, are spawning between June and August, and that YOY sheepshead inhabit the bay from July through November. These significant differences in vital rates, along with the presence of spawning females and YOY, indicate that the sheepshead population of the Chesapeake Bay are a unique stock. Using the vital rates of the sheepshead of Chesapeake Bay, we estimated biological reference points and developed a preliminary management plan for the sheepshead. This plan attempted to provide both a maximum yield for the yield-based commercial fishery and trophy fish for the recreational fishery while preventing occurrence of overfishing (recruitment and growth overfishing), and it has been submitted to VMRC for consideration (Please contact CQFE or VMRC for details). Currently, we are examining sheepshead reproductive status and fecundity in Chesapeake Bay. We will develop a final management plan for sheepshead fisheries once the study is completed.

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Table 1. The number of sheepshead assigned to each total length-at-age category for 467 fish sampled in Virginia in 2006-2008.

Length 1-inch interval	Age (years)										
	0	1	2	3	4	5	6	7	8	9	10
<1	1	0	0	0	0	0	0	0	0	0	0
1	9	0	0	0	0	0	0	0	0	0	0
2	10	0	0	0	0	0	0	0	0	0	0
3	39	0	0	0	0	0	0	0	0	0	0
4	19	0	0	0	0	0	0	0	0	0	0
5	18	0	0	0	0	0	0	0	0	0	0
6	17	0	0	0	0	0	0	0	0	0	0
7	16	1	0	0	0	0	0	0	0	0	0
8	3	3	0	0	0	0	0	0	0	0	0
9	0	3	1	0	0	0	0	0	0	0	0
10	0	0	4	0	0	0	0	0	0	0	0
11	0	0	4	1	0	0	0	0	0	0	0
12	0	0	3	1	0	0	0	0	0	0	0
13	0	0	3	2	0	0	0	0	0	0	0
14	0	0	1	2	0	0	0	0	0	0	1
15	0	0	0	3	1	0	0	1	0	0	0
16	0	0	0	1	1	0	0	0	0	0	0
17	0	0	0	2	1	5	1	0	1	1	0
18	0	0	0	0	1	9	2	2	1	1	2
19	0	0	0	0	0	8	4	3	0	1	1
20	0	0	0	0	1	9	8	6	5	3	4
21	0	0	0	0	2	1	5	8	6	6	4
22	0	0	0	0	0	0	3	3	5	13	12
23	0	0	0	0	0	0	0	1	3	8	6
24	0	0	0	0	0	0	0	0	1	2	1
25	0	0	0	0	0	0	0	0	0	0	1
26	0	0	0	0	0	0	0	0	0	0	1
Totals	132	7	16	12	7	32	23	24	22	35	33

Table 1. Continued.

Length 1-inch interval	Age (years)										
	11	12	13	14	15	16	17	18	19	20	21
<1	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	0	1	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0
20	1	1	1	1	0	0	0	0	0	0	0
21	1	0	2	1	0	0	0	1	0	0	0
22	4	3	0	2	2	5	3	2	1	0	0
23	5	1	3	1	5	5	1	4	1	0	0
24	7	0	2	5	4	2	2	3	0	2	2
25	2	0	0	0	2	1	3	0	1	2	1
26	0	0	0	0	0	0	0	0	0	0	0
Totals	20	6	8	10	13	13	9	10	3	4	3

Table 1. Continued.

Length 1-inch interval	Age (years) 22	23	24	25	26	29	30	32	33	34	35	Totals
<1	0	0	0	0	0	0	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	0	9
2	0	0	0	0	0	0	0	0	0	0	0	10
3	0	0	0	0	0	0	0	0	0	0	0	39
4	0	0	0	0	0	0	0	0	0	0	0	19
5	0	0	0	0	0	0	0	0	0	0	0	18
6	0	0	0	0	0	0	0	0	0	0	0	17
7	0	0	0	0	0	0	0	0	0	0	0	17
8	0	0	0	0	0	0	0	0	0	0	0	6
9	0	0	0	0	0	0	0	0	0	0	0	4
10	0	0	0	0	0	0	0	0	0	0	0	4
11	0	0	0	0	0	0	0	0	0	0	0	5
12	0	0	0	0	0	0	0	0	0	0	0	4
13	0	0	0	0	0	0	0	0	0	0	0	5
14	0	0	0	0	0	0	0	0	0	0	0	4
15	0	0	0	0	0	0	0	0	0	0	0	5
16	0	0	0	0	0	0	0	0	0	0	0	2
17	0	0	0	0	0	0	0	0	0	0	0	11
18	0	0	0	0	0	0	0	0	0	0	0	19
19	0	0	0	0	0	0	0	0	0	0	0	17
20	0	0	0	0	0	0	0	0	0	0	0	40
21	0	0	0	0	0	0	0	0	0	0	0	37
22	1	1	1	0	0	0	0	0	0	0	0	61
23	1	2	1	1	0	1	0	0	0	0	0	50
24	0	1	1	1	1	0	0	0	1	1	2	41
25	0	2	2	1	0	0	1	1	0	0	0	20
26	1	0	0	0	0	0	0	0	0	0	0	2
Totals	3	6	5	3	1	1	1	1	1	1	2	467

Table 2. Age-Length key, as proportion-at-age in each 1-inch length interval, based on otolith ages for sheepshead sampled in Virginia in 2006-2008.

Length 1-inch interval	Age (years) 0	1	2	3	4	5	6	7	8	9	10
<1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.941	0.059	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.750	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.800	0.200	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.750	0.250	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.600	0.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.250	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.250
15	0.000	0.000	0.000	0.600	0.200	0.000	0.000	0.200	0.000	0.000	0.000
16	0.000	0.000	0.000	0.500	0.500	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.182	0.091	0.455	0.091	0.000	0.091	0.091	0.000
18	0.000	0.000	0.000	0.000	0.053	0.474	0.105	0.105	0.053	0.053	0.105
19	0.000	0.000	0.000	0.000	0.000	0.471	0.235	0.176	0.000	0.059	0.059
20	0.000	0.000	0.000	0.000	0.025	0.225	0.200	0.150	0.125	0.075	0.100
21	0.000	0.000	0.000	0.000	0.054	0.027	0.135	0.216	0.162	0.162	0.108
22	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.049	0.082	0.213	0.197
23	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.020	0.060	0.160	0.120
24	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.024	0.049	0.024
25	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.050
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.500

Table 2. Continued.

Length 1-inch interval	Age (years) 11	12	13	14	15	16	17	18	19	20	21
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.053	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.025	0.025	0.025	0.025	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.027	0.000	0.054	0.027	0.000	0.000	0.000	0.027	0.000	0.000	0.000
22	0.066	0.049	0.000	0.033	0.033	0.082	0.049	0.033	0.016	0.000	0.000
23	0.100	0.020	0.060	0.020	0.100	0.100	0.020	0.080	0.020	0.000	0.000
24	0.171	0.000	0.049	0.122	0.098	0.049	0.049	0.073	0.000	0.049	0.049
25	0.100	0.000	0.000	0.000	0.100	0.050	0.150	0.000	0.050	0.100	0.050
26	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 2. Continued.

Length 1-inch interval	Age (years) 22	23	24	25	26	29	30	32	33	34	35
<1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
18	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
22	0.016	0.016	0.016	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
23	0.020	0.040	0.020	0.020	0.000	0.020	0.000	0.000	0.000	0.000	0.000
24	0.000	0.024	0.024	0.024	0.024	0.000	0.000	0.000	0.024	0.024	0.049
25	0.000	0.100	0.100	0.050	0.000	0.000	0.050	0.050	0.000	0.000	0.000
26	0.500	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 3: Summary of the various yield-per-recruit models assessed for sheepshead management. MLL=minimum length limit, $F_{OFL}=F_{0.1}$ from the yield per recruit model, YPR=yield-per-recruit, % of F_{max} Yield=% of realized yield per recruit using either F_{OFL} or F_{ABC} in comparison to the maximum yield-per-recruit, T_r=time to recruitment to the fishery, $F_{ABC}=0.75*F_{0.1}$, % Cohort Harvested=% of cohort harvest if fished at F_{OFL}, and % Cohort Trophy=% of a given cohort that will attain trophy length (22" TL) during their life span.

MLL (in)	F_{OFL}	YPR	% of F_{max} Yield	T_r (yr)	
18	0.151 to 0.211	1.055 to 1.426 kg	88 to 91%	4	
19	0.163 to 0.236	1.071 to 1.454 kg	87 to 89%	5	
20	0.174 to 0.261	1.066 to 1.466 kg	85 to 87%	6	
21	0.186 to 0.288	1.030 to 1.451 kg	82 to 84%	7	
22	0.211 to 0.315	0.938 to 1.403 kg	80 to 82%	8	
MLL (in)	**F_{ABC}**	**YPR**	**% of F_{max} Yield**	**% Cohort Harvested**	**% Cohort Trophy**
18	0.113 to 0.158	0.981 to 1.331 kg	82 to 85%	36 to 45%	14 to 27%
19	0.122 to 0.177	0.984 to 1.344 kg	80 to 82%	35 to 44%	15 to 28%
20	0.131 to 0.196	0.989 to 1.344 kg	79 to 80%	32 to 42%	17 and 31%
21	0.140 to 0.216	0.954 to 1.336 kg	76 to 78%	29 to 39%	22 to 37%
22	0.158 to 0.236	0.866 to 1.293 kg	74 to 75%	24 to 36%	33 to 49%